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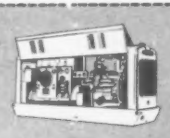
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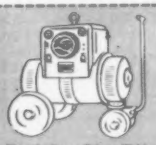
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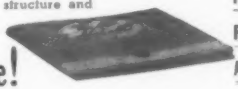

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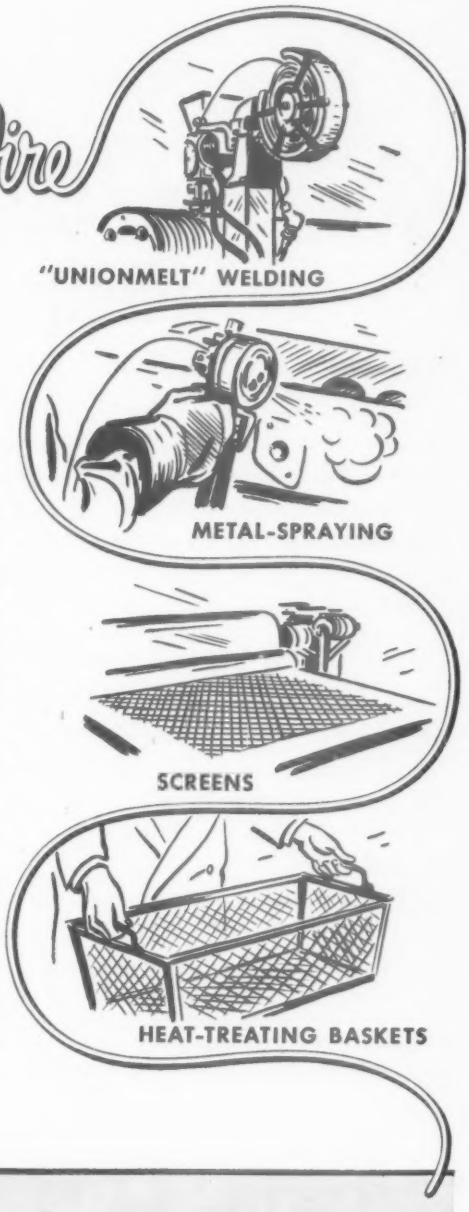

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The WELDING JOURNAL

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Inert Gas-Shielded Arc Spot Welding

In this new inert gas-shielded arc spot welding the weld is produced by the heat of an electric arc

by F. J. Pilia

INTRODUCTION

THE purpose of this paper is to introduce to the metal-working industry, a new process of spot welding, namely, inert gas-shielded arc spot welding. The weld is produced by the heat from an electric arc applied to the top surface of two lapped pieces of metal. The welding action is controlled by the current input to the arc and the time the arc is allowed to dwell upon the material to be welded. The arc, tungsten electrode and fluid puddle are shielded with an inert gas, in a manner similar to that employed in the conventional inert gas-shielded arc welding process.

A resistance spot weld is produced by the effect of high current and pressure applied to the electrodes, while a gas-shielded spot weld is produced with fusion alone. Since no forging pressure is required on the fused nugget, consequently no backup or access to the reverse side of the weld is necessary. This accounts for one of the major advantages of the gas-shielded—or heliarc—spot welding process—the ability to produce spot welds from one side of the joint only.

The apparatus required for the heliarc spot welding operation consists of a standard 60-cycle, a.-c. metal-arc welding transformer with a built-in high-frequency unit. The transformer preferably should have power factor correction. A timing device similar to that used for resistance spot welding is employed, except that longer time cycles are required for the arc, and instead of circuits for "squeeze" and "hold," there is a circuit for argon shutoff delay.

The actual tool for performing the weld consists of a gun of molded plastic about the size of a Colt "45" automatic. The gun is equipped with a water-cooled copper cup which bears against the workpiece. A tungsten electrode from which the electric arc issues is located centrally in this cup. It is spaced back from the end of the cup by approximately $^3/_{32}$ of an inch. This setting varies with the materials being welded and is adjustable from the working end of the cup.

Argon gas is distributed through a series of orifices in the electrode holding mechanism, and is allowed to flow smoothly through the interior of the cup, shielding the electrode, the arc and the material being welded. Four V shaped notches at the base of the cup allow for purging the atmosphere of the cup and for dispelling gases contaminated by welding. The cup is completely insulated from the current-carrying members of the gun.

Three hose and one switch cord are encased in a rubber jacket approximately 25-ft. long to supply the welding current, cooling water, argon gas and trigger control of the gun. This cable assembly is extremely flexible and rugged, being capable of withstanding considerable abrasion and rough handling on shop floors.

A typical cycle of operation is as follows: Two pieces of metal approximately 0.040-in. thick are lapped as a weld sample. The cup of the gun is brought to bear against the top of the two pieces. The trigger on the gun is depressed momentarily, closing the main contactor on the power supply to the welding transformer. As the primary contactor closes, the argon solenoid valve in the timing device is opened to allow for the flow of argon gas to the cup of the gun. The high-frequency current which is superimposed upon the welding circuit after the trigger has been depressed ionizes a path between the electrode and the workpiece, and allows the 60-cycle welding current arc to initiate the electric arc required for the weld.

At the time that the welding current begins to flow, a relay in the welding current circuit closes, initiating a preset timing cycle through either a mechanical clock or electronic timer. At the end of the correct time interval, the primary contactor on the welding transformer opens and extinguishes the arc. A second timer then continues the flow of argon to allow the electrode to cool

F. J. Pilia is a Development Engineer with The Linde Air Products Co., Newark, N. J.

This paper was presented at the Twenty-Ninth Annual Meeting, A.W.S., Philadelphia, Pa., week of Oct. 24, 1948.

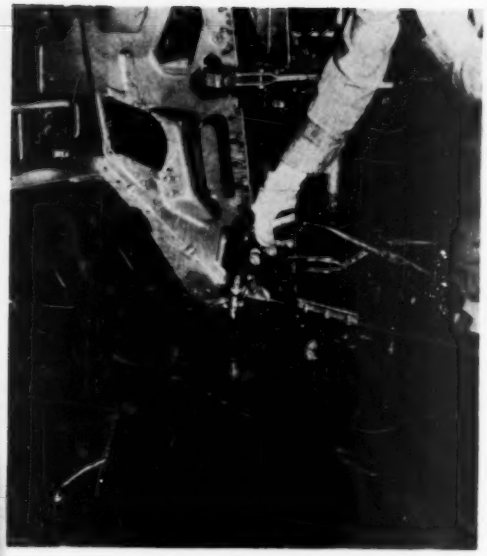

Fig. 1 Spot welding front door post to floor pan in framing jig

in an argon atmosphere. The cooling time is usually 10 to 15 sec. for a $^1/_8$-in. diam. tungsten electrode. The welding cycle cannot be repeated until the trigger has been released and the arc has been extinguished. This prevents unintentional refiring or time cycles longer than those which have been preset on the timer.

APPLICATION OF PROCESS

As many well know, the automobile body is designed primarily around the resistance spot-welding process with some use of oxy-acetylene welding, metal-arc welding and flash welding. Metal-arc welding in body construction is used where resistance spot welding is not feasible due to the size of the machine required, the obstruction of the work or inability to reach the opposite side of the work for resistance welding backup.

The heliarc spot welding process answers most of the problems on body construction which until now have been solved by using metal-arc welding. Although either process can be used on locations where no backup is available, heliarc spot welding is faster, easier and requires no particular skill or training. The size and flexibility of the gun makes it particularly well suited for use on obstructed work. By comparison, a single heliarc spot weld in 0.037-in. deep-drawing mild steel produces the same mechanical properties as a metal-arc weld $^3/_4$-in. long or an oxy-acetylene weld $^1/_2$-in. long.

This process is particularly advantageous in the framing jig because the equipment is extremely portable, the spot welds are dependable and the gun can be used by nonskilled labor. These factors make it an ideal tool for the assembly lines.

Because the arc is confined primarily within the cup, only flash glasses or plastic face shields are required for protection of the operators. As this process produces no toxic fumes, smoke or spatter, welding booth and ventilating systems are not required. Also, due to the portability of the apparatus, extreme lightness, compactness and flexibility in relatively inaccessible spots, the number of spots produced per hour can be greater than that produced with the large and cumbersome special spot-welding units required to reach such places.

Another application which is particularly suited for the process is the production of spots which are subsequently covered with body solder. Previously, with metal-arc welding on this type of joint design, it has been necessary to grind the metal-arc weld flush or below the intended surface of the solder fill. With the heliarc spot-welding process, the grinding-operation is eliminated. The welds produced are relatively flat and require no further preparation prior to filling with solder.

The following illustrations show the application of the process to automobile body fabrication under the conditions previously described. These photographs are made available through the courtesy of the Briggs Manufacturing Co. and show steps in the fabrication of the two- and four-door 1948 models of a well-known make of car.

Figure 1 shows the welding of the front door post assembly to the floor pan in the framing jig. These welds were previously made by metal arc. While the joint design is ideal for resistance welding, it was not considered practical because of the size of the unit required to

Fig. 2 Fire wall and windshield frame are joined to the front assembly by heliarc spot welds

reach around the sections of the body to be welded. The small, round holes visible in this panel were provided for metal-arc plug welding. Note that the operator has the cup of the gun placed firmly against the sheet being welded and that there is no objectionable glare, smoke or spatter from the operation. The operator is wearing a plastic face shield with a light green shaded top and a clear portion at the bottom.

Figure 2 shows the welding of the front assembly consisting of the fire wall and windshield frame for a convertible-type car. This is a typical example of welds that would be difficult to back up for resistance welding due to obstruction by structural sections behind the weld.

Body brackets are welded to the floor pan shown in Fig. 3. The bracket is made of 0.064-in. material and in this particular operation the weld is being made on the edge of the bracket, the cup being placed halfway

Fig. 3 Body brackets are joined to the floor pan by spot welds

over the edge of the bracket. This produces a weld similar to a gas-weld tack. Note that the body is on a wheeled dolly and is proceeding down the line during the welding.

The cross-bracing for the rear seat of the four-door model is welded to the floor pan at the lower ends of the diagonals and center brace. In two-door models, a side stiffening member is welded to the floor pan as shown in Fig. 4. The light priming paint on the floor pan does not interfere with the production of the weld.

The welding of a side panel assembly to the floor pan

Fig. 4 In two-door models, a side stiffening sheet is welded to the floor pan

in the framing fixture is shown in Fig. 5. Usually two heliarc spot welds are made on this flange in the fixture and the balance of the welds are made after the body is removed from the fixture and is proceeding down the line. A few carefully selected spots properly located during body framing eliminate much of the poor fitup usually encountered on the line. This particular flange without the welds would open approximately $^3/_{16}$ to $^1/_4$ in. upon being removed from the framing jig. Two welds on each flange completely eliminate this separation. The hose assembly which carries welding current, water, gas and switch control are all encased within the rubber jacket.

The process is used for reinforcement of resistance welds. For this purpose approximately four welds are spaced along the door sill joint shown in Fig. 6. These reinforcing welds were previously made by metal arc.

Figure 7 shows the use of the process to replace metal-arc tack welds on the front assembly. These welds are

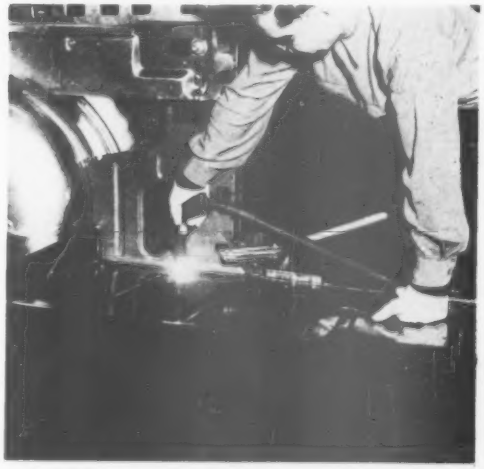

Fig. 5 Welding the side panel assembly to the floor pan as the body is assembled in the framing jig

subsequently covered with body solder and so must be flush or slightly lower than the surrounding surface. When metal-arc welding was used, the welds required grinding to remove the excess weld metal. With heliarc spot welding, no grinding is necessary.

The necessary equipment for inert heliarc spot welding is shown in Fig. 8. This is a typical installation consisting of a metal-arc welding transformer of 250-amp. capacity with a built-in high-frequency unit and power factor correction. The electronic timing device, the power supply fuse box and main disconnect switch are to the right. Just behind the leading edge of the next body is visible the inert-gas cylinder and pressure-regulating mechanism. The two pipes to the rear of the fuse box are the water inlet and drain. The ground wire from the welding transformer is connected directly to the metal conveyor system on which the bodies ride.

In addition to the automotive operations, the process has been successfully used in attaching light sections to very heavy sections. It is entirely possible to attach 0.040-in. sheet to a 4-in. thick section in the various metals. Because of this, the process is practical for applying stainless steel liners to mild steel pressure vessels. The surface of the mild steel should be free from mill scale, rust or dirt, and the liner must contact the mild steel in the vicinity of the weld during the welding operation. Welds can be made on this type of construction in the flat, vertical and overhead positions.

Heliarc spot welds in stainless steel have the same corrosion resistance as heliarc continuous welds. In those materials subject to carbide precipitation, the zone of precipitation around the weld will be extremely narrow due to the quenching effect of the heavier mass behind the weld. Weld time and current cycles can be set up so that very little dilution of the stainless steel liner by the mild steel backup occurs. In fact, this dilution can be restricted to the area of juncture between the mild steel and stainless steel.

Fig. 7 Joining the windshield frame to the rest of the front assembly. This location is subsequently covered with body solder

Fig. 6 Heliarc spot welds along the door sill are insurance against the failure of resistance spot welds

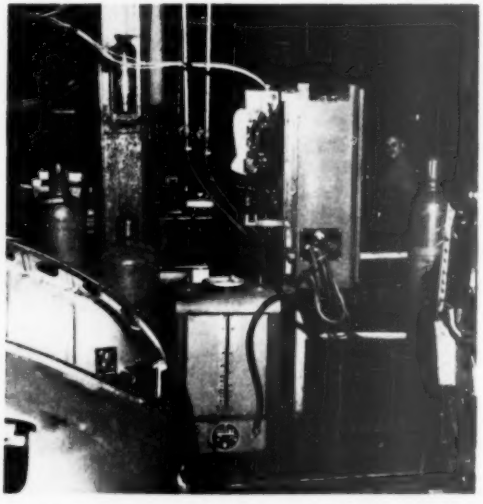

Fig. 8 Equipment for heliarc spot welding consists of transformer, timing control unit, argon cylinder with regulator and flowmeter and hoses for water cooling

The process can be used satisfactorily to attach the top sheet to a corrugated sandwich, such as is used in the manufacture of trailers and railway equipment. A corrugated sandwich is made by resistance welding the tops of the corrugated sheet to one of the side sheets. When attaching the final sheet to the sandwich, difficulty due to the inaccessibility of the reverse side of the corrugation makes resistance welding impractical for the final operation. Heliarc spot welding has been used on these operations with very satisfactory results. Sandwiches have been made employing as many as 700 welds in this manner for the final assembly.

Due to the portability, visibility and lack of skill required, this tool becomes extremely useful for railway car and automotive trailer repair service especially for stainless steel bodies and parts. Although many of these structures were originally fabricated with resistance welding, when repairs are necessary, resistance welding is usually impractical, due to the specialized units that would be required for the individual repair. In many cases, resistance welding cannot be used at all because the reverse side of the section to be welded cannot be reached for backup. For such repairs, it is merely necessary to install a patch or repair from the outside of the structure and use heliarc spot welding for the final joint.

With an increase in availability of apparatus, it is conceivable that the automotive shops will also find wide application for the process in other repair work.

Metal furniture and cabinets can be easily fabricated by this process because the equipment is so portable and the gun can be used in very limited spaces. Manufacturers of such widely diversified objects as outdoor display signs, home appliances, and food handling equipment will find wide use for the process. Mild steel and stainless steel in thicknesses up to 0.078 in. are being successfully welded in production. Aluminum materials up to 0.064-in. thick can also be welded with the same speed and satisfactory results.

Welding conditions for aluminum are somewhat different from those of mild steel and stainless steel. Due to the conductivity of aluminum, it is necessary that the sheets be in very intimate contact, in order to obtain consistent and satisfactory results. To obtain the required fitup, some means must be employed to back the reverse side of the weld. In the case of large structures, this may be done by a bucking bar held by a helper. Where smaller objects are made on a production basis, blocks can be located in a fixture to back the weld.

One rather unique feature of the process is the fact that it is possible to control the current and time settings so that welds can be made without disturbance to the reverse side of the sheet being welded. As an example of this, it was possible to produce five spot welds on an aluminum refrigerator vegetable bin assembly, in which the reverse side of the spots was exposed and painted with a high gloss enamel. When resistance spot welding was used for this operation, considerable finishing of the aluminum was required in order to remove all evidence of the spot welds. Heliarc spot welding was used without the necessity of this finishing operation.

Surface conditions of aluminum materials require special attention when heliarc spot welding is applied. Oxides, carbonaceous materials and surface dirt must be entirely removed before welding. Chemical cleaning, vapor blasting or scratch brushing will produce satisfactory surfaces.

Table 1

Test	*Gage*	*Material*	*Inert gas*	*Resistance weld*
Tension shear	0.020	Stainless steel	1236 lb.	600 lb.
Static	0.060	Stainless steel	5018 lb.	3400 lb.
Pounds to failure	0.032	Carbon steel	1115 lb.	700 lb.
	0.045	Carbon steel	1320 lb.	1250 lb.
	0.057	Carbon steel	2150 lb.	1800 lb.
	0.094	Carbon steel	3318 lb.	3800 lb.
Direct tension	0.020	Stainless steel	580 lb.	500 lb.
Static	0.060	Stainless steel	1986 lb.	2000 lb.
Pounds to failure	0.032	Carbon steel	290 lb.	575 lb.
	0.045	Carbon steel	566 lb.	1600 lb.
	0.057	Carbon steel	1083 lb.	1560 lb.
	0.094	Carbon steel	1850 lb.	2300 lb.
Tension shear	0.020	Stainless steel	33.2 ft.-lb.	3.3 ft.-lb.
Impact	0.060	Stainless steel	154.0 ft.-lb.	39.0 ft.-lb.
Foot-pounds	0.032	Carbon steel	42.5 ft.-lb.	34.0 ft.-lb.
	0.045	Carbon steel	61.2 ft.-lb.	90.0 ft.-lb.
	0.057	Carbon steel	83.2 ft.-lb.	150.0 ft.-lb.
	0.094	Carbon steel	117.2 ft.-lb.	220.0 ft.-lb.
Direct tension	0.020	Stainless steel	12.1 ft.-lb.	2.0 ft.-lb.
Impact	0.060	Stainless steel	49.1 ft.-lb.	34.0 ft.-lb.
Foot-pounds	0.032	Carbon steel	5.8 ft.-lb.	10.0 ft.-lb.
	0.045	Carbon steel	9.2 ft.-lb.	25.0 ft.-lb.
	0.057	Carbon steel	43.0 ft.-lb.	40.0 ft.-lb.
	0.094	Carbon steel	44.2 ft.-lb.	100.0 ft.-lb.
Diameters	0.020	Stainless steel	0.28 in.	0.100 in.
Inches	0.060	Stainless steel	0.30 in.	0.220 in.
	0.032	Carbon steel	0.14 in.	0.15 in.
	0.045	Carbon steel	0.18 in.	0.18 in.
	0.057	Carbon steel	0.22 in.	0.20 in.
	0.094	Carbon steel	0.28 in.	0.27 in.

Table 2

Welding Machine: 75-Kva. Federal Spot and Projection Welder.
Electrodes: $^5/_8$-in. diam. Class II electrodes with 3-in. radius tips.
Sample Material: $1^1/_2$- by 5-in. pieces of 16-gage (0.062-in.) and 14-gage (0.078-in.) Type 304 hot-rolled, annealed and pickled stainless steel, edges as sheared, cleaned in hot perchlorethylene to remove dirt and grease but otherwise given no other surface preparation.
Welding Machine Settings and Test Results:

Sample	*Electrode force, lb.**	*Welding current, amp.*	*Weld Time, cycles*	*Hold Time, cycles*	*Remarks on weld*	*Tension-shear values, lb.*
1	1700	11,600	10	10	.....	2262
2	1700	11,600	10	10	.....	2450
3	1700	11,600	10	10	.....	2600
4	1700	11,200	10	10	.....	2370
5	1700	11,200	10	10	.....	2275
6	1700	11,200	10	10	.....	2350
7	1700	10,800	10	10	.....	2260
8	1700	12,000	10	10	.....	2580
9	1700	12,000	10	10	.....	2530
10	1700	12,000	10	10	.....	2257
11	1700	12,500	10	10	.....	2780
12	1700	12,500	10	10	Slight expulsion	2900
13	1700	12,500	10	10	.....	2690
14	1700	12,900	10	10	Slight expulsion	2890
15	1700	12,900	10	10	Considerable expulsion	2635
16	1700	13,300	10	10	Considerable expulsion	2550

* Electrode force indicated is probably slightly higher than the value for net electrode force because of friction in the air cylinder and on the ram ways.

NOTE: All samples tested broke in shear through the spot weld. Samples 9 through 16 had a shrinkage cavity in the center of the weld nugget and those samples with the higher current settings had larger shrinkage cavities.

PHYSICAL PROPERTIES OF INERT GAS-SHIELDED ARC SPOT WELDS

Depending upon the material thickness, welding conditions and rapidity of operation, cost per spot ranges between 1 to 4 mills and welding times range around $^1/_2$ to $\frac{6}{}$ sec. per spot. Weld rejects, due to weld failures, average about $1^1/_2$%. Malformed welds due to electrode contamination with the weld puddle and burn-throughs due to sheet separation and extremes in power factor variation average 4.2% rejects. Table 1 gives physical properties for various thicknesses of mild steel and stainless steel, for spot welds as made by the heliarc process and standard resistance welding.

The direct tension static samples of the heliarc spot welds have lower values than the resistance spot welds. In all other kinds of tests, however, they very closely approximate the generally accepted resistance spot-welding values.

Comparisons were made on 14 and 16 gage, Type 304 stainless steel of heliarc welds to resistance welds. Table 2 gives the welding conditions and test data for resistance welding. Table 3 gives the welding conditions and test data for heliarc spot welding.

CONCLUSIONS

Heliarc spot welding has several inherent advantages

Table 3

Welding Machine: Linde's Heliarc Spot Welder, 400-Amp, Miller, High-Frequency Stabilized A.-C. Welder.
Electrode: $^1/_8$-in. tungsten electrode.
Specimen Material: $1^1/_2$- by 5-in. pieces of 16-gage (0.062-in.) and 14-gage (0.078-in.) Type 304 hot-rolled, annealed and pickled stainless steel. The specimens were cleaned with emery paper prior to welding.
Welding Machine Settings and Test Results:

Sample	*Argon flow, liter per minute*	*Arc time, sec.*	*Amp.*	*Tension-shear values, lb.*	*Remarks*
1	4	2	250	500	Spot shear
2	4	2	250	2145	Spot shear
3	4	2	275	2050	Spot shear
4	4	2	275	1350	Spot shear
5	4	$2^1/_2$	250	3230	Approx. $^5/_{16}$-in. button
6	4	$2^1/_2$	250	3565	Approx. $^3/_8$-in. button
7	4	$2^1/_2$	275	3060	Spot shear
8	4	$2^1/_2$	275	3420	Approx. $^3/_8$-in. button
9	4	3	225	3640	Approx. $^3/_8$-in. button
10	4	3	225	3660	Approx. $^3/_8$-in. button
11	4	2	250	3000	Approx. $^3/_{16}$-in. button
12	4	2	250	2720	Spot shear
13	Did not weld	Did not weld			
14	4	3	225	3750	Approx. $^3/_8$-in. button
15	4	3	225	3200	Approx. $^3/_8$-in. button

NOTE: All specimens broke as indicated in column headed "Remarks." Those marked "spot shear" broke tearing out no metal. Those marked "button" tore out metal to the approximate indicated diameters.

which make the process ideally suited for production welding. The ability to join two pieces of metal in the lapped condition from one side of the sheet only is one of its outstanding features. The extreme portability of the apparatus, makes it possible to take the apparatus to the job conveniently rather than the job to the apparatus, and thus the process is ideally suited for production line work. Heliarc spot welding equipment is considerably more portable than the conventional resistance spot-welding guns. The heliarc gun only weighs 2 lb. and the cables and hose necessary for its operation are encased within a hose sheath approximately $1^1/_{16}$ in. in diameter. The welding cable in this assembly is only 10,000 circular mils in diameter. The total assembly is about as light and flexible as a piece of 4/0 welding cable. This compares to the portable resistance spot-welding guns that weigh upwards of 40 lb. and have two welding cables of several hundred thousand circular mils to carry the 5000 to 10,000 amp. required to make a weld, as well as air, water and control wire. The length of cable on the heliarc spot-welding gun is 25 ft. as compared to a maximum of 8 ft. on a resistance welding gun.

The fact that the process does not require skilled operators makes it possible to use it on conventional assembly lines without delay. The low power demand by the welding transformer as compared to the power demand for resistance spot welding guns makes it extremely attractive for shops already overburdened with spot-welding equipment. The portability of the gun and the fact that the welds are made from only one side of the sheet make it possible to eliminate the cumbersome and costly special guns that would be required for resistance spot welding certain parts of the assemblies. These facts also make it possible to use one gun on several or all of the welds within the reach of one operator and also help to standardize on spare parts and equipment, resulting in a minimum of service time and ease of replacement problem.

The heliarc spot-welding process does not and is not intended to compete with resistance spot welding under conditions favorable to resistance spot welding. Due to the cost of the shielding gas and the longer time cycles involved, such competition is impractical. The process, however, does fill a very conspicuous gap between resistance welding and fusion welding, such as metal-arc welding and oxy-acetylene welding. In the case of the latter two, the heliarc spot-welding process replaces the fusion welding processes because of lower cost.

Heliarc spot welding is a new process and a new tool for the metal-working industry. It should develop into as important a process as the resistance welding process, metal-arc welding process, oxy-acetylene welding process and the various other generally accepted welding processes for the metal-working industry.

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Adams Lecture

The Metallurgy of Covered Electrode Weld Metal

Further advances in arc welding can be made on the basis of comprehensive studies of slags, their functions and control. The author points the way

by G. E. Claussen

MR. CHAIRMAN, members and guests of THE AMERICAN WELDING SOCIETY gathered here to do honor to Dr. Comfort A. Adams. In view of the facts that Dr. Adams is a leader in research and that this lecture will describe a particular phase of welding research, it is only natural to begin with a few words about welding research in general. There is a universal tendency among the weaker of us mortals to ignore something we know nothing about. This tendency can be observed in welding as in other matters. Everyone knows that the weld bead deposited by a covered electrode is covered with a slag. But we do not know much about that slag nor about its interaction with the weld metal. Consequently, we are content to brush off the slag, take it for granted and admire the weld. During the past fifteen years we have learned a great deal about welds, but about the slags under which these welds solidified very little has been published.

Once the matter is brought to your attention you ask, "Why has the slag been ignored in our studies of weld metal?" The answer seems to be that the slag was ignored or was considered inconsequential, because nothing was known about it. Looking back over the history of welding, we find this sort of situation has occurred periodically in the development of all our common welding processes.

No one has been so influential in clarifying these situations in welding as Dr. Adams. Throughout his association with welding he has pointed to inequalities in our knowledge of welding processes and weld properties. Not only has he directed attention to fruitful avenues of research that have been overlooked, but in many instances he has devoted his own efforts and his own resources to the research itself.

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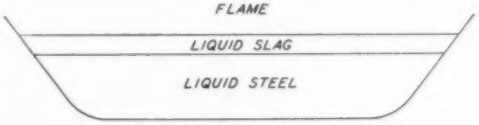
This lecture was presented at the Twenty-Ninth Annual Meeting, A.W.S., Philadelphia, Pa., week of Oct. 24, 1948.

In selecting a topic for this lecture, I have endeavored to divine what Dr. Adams might have selected in my position. The subject of the metallurgy of covered electrode weld metal, with particular reference to slag-metal problems, seemed to be appropriate. Slag-metal reactions are fundamental to the production of weld metal, yet there is scarcely any published information concerning them. Slags from covered electrodes are derived from coatings which in the past have been treated as trade secrets. Furthermore, the conditions of arc welding and the compositions of the slags are sufficiently different from steelmaking slags that direct application of steelmaking results to arc-welding slags has not been attempted. It is the purpose of this lecture to show some points of similarity and difference between slags in steel refining furnaces and slags in arc welding with covered electrodes, using phosphorus and sulphur as elements for study.

Before comparing steelmaking with weld deposition, let us examine the principal steelmaking processes. The most widely used is the basic open hearth, Fig. 1, in which 100 tons or so of liquid steel rests on a refractory hearth. During the refining period of eight hours, carbon, manganese, silicon, phosphorus and sulphur are removed from the metal to a great extent. Carbon leaves the furnace as a gas, CO or CO_2, but the other elements are held in the slag. The extent to which the elements in the bath are removed to the slag is expressed by a distribution ratio. For example, if



	FURNACE	WELD
DEPTH OF SLAG	1	1
DEPTH OF STEEL	6	4

Fig. 1 Basic open-hearth furnace

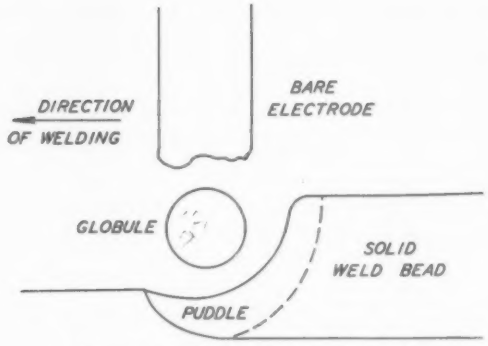


Fig. 2 Arc welding with a bare electrode

a slag contains 0.60% S and the metal beneath contains 0.20% S, the distribution ratio for sulphur is 0.60/0.20 = 3. The distribution ratio for a given element depends on the composition of the slag and steel, and on temperature, but not on the weights of slag and steel.

The basic open hearth is so named because slag and hearth are basic, that is principally lime (CaO) or magnesia (MgO). Opposite in character to the basic process is the acid open hearth, so named because the slag and hearth are acid, that is, principally silica (SiO_2). In the acid open hearth only carbon and manganese are removed from the metal.

The electric arc furnace more closely resembles the weld puddle than the open hearth only in the sense that an arc is used as source of heat. In other respects, such as slag thickness and relative absence of circulation in the steel, the basic and acid electric processes resemble the open hearth. The arc is drawn between carbon electrodes, but the steel adjacent to the arc is not heated to the extremely high temperature of the arc. In fact, steel temperature is no higher in arc furnaces than in other steelmaking furnaces.

The Bessemer process, in which air is forced through liquid pig iron to remove carbon, is similar in some respects to welding with a bare electrode. During welding with a bare electrode the globules of liquid steel pass through air, Fig. 2, instead of air being passed through the steel. Both processes lead to the same result. First, carbon is rapidly burned out of the metal, after which the iron dissolves oxygen and is converted to iron oxide. There is practically no slag in either the Bessemer process or in welding with bare electrodes. The Bessemer steel and also the weld metal are in contact with air, and no slag-metal distributions apply. Instead, a gas-metal distribution ratio may be imagined, oxygen and nitrogen being the gases. A part of the oxygen and nitrogen of the air passes into the steel and weld.

The last steel refining process we shall consider is the Perrin process, still largely experimental. In this process the steel to be dephosphorized is poured from a height of 15 ft. into a ladle containing molten basic slag (60% CaO, 30% FeO + Fe_2O_3, 10% SiO_2) amounting to 10% of the weight of the steel. The close contact of steel with slag during pouring reduces the time for dephosphorization, that is, attainment of high phosphorus distribution ratios, from perhaps an hour in an open hearth to five minutes in the Perrin process. The mixing of steel with slag in this process is characteristic also of welding with covered electrodes, Fig. 3.

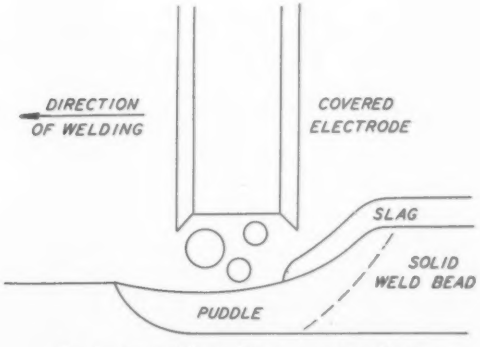


Fig. 3 Arc welding with a covered electrode

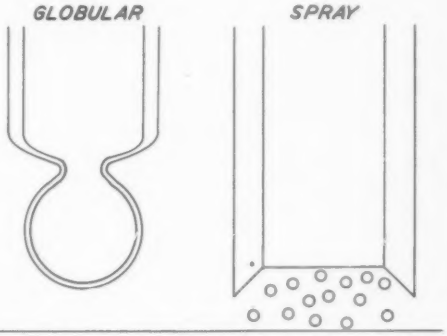


Fig. 4 Two types of weld metal transfer with covered electrodes

The mechanism by which steel and slag mix in welding is not understood completely. During globular transfer, Fig. 4, either the slag coats each globule, which has about the same diameter as the core rod, or, less probably, the slag transfers independently. In spray transfer there is the same uncertainty. It is certain, however, that slag and steel are well mixed during both types of transfer.

Although the time of contact of liquid steel with liquid slag in arc welding is only 1 to 5 sec., the intimacy of contact offsets the short time, and makes it possible that distribution ratios applicable to steel refining might apply to welding, too.

EXPERIMENTAL METHOD

To study slag-metal reactions with covered, extruded electrodes, slag was collected from beads deposited in

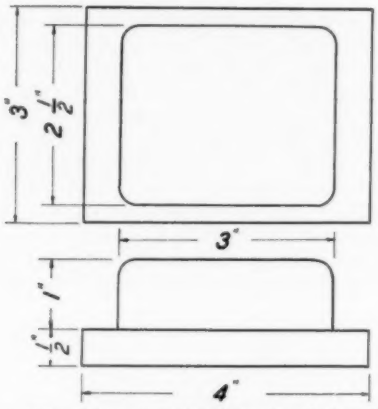


Fig. 5 Dimensions of weld pad for chemical analysis

the form of a pad, Fig. 5. The welding was done in most experiments with $^5/_{32}$-in. electrodes with overlapping beads and a maximum weave of $2^1/_2$ core diameters. No slag or metal for analysis was collected from the first three layers in order to avoid dilution by plate metal. After each bead of subsequent layers was completed, the slag was removed with a hammer and was collected for analysis. The pad was cooled in hot water and was chipped to remove spatter after every bead.

Upon completion of the pad it was drilled from the top to within $^3/_8$ in. of the surface of the plate to collect chips for analysis. The slag was crushed and passed through a 100-mesh screen. The metallic portion of the slag was in the form of spherical globules, which were removed by a magnet. An indication that the metallic portion of the slag was completely removed by the crushing and screening operation is provided by the fact that spattery and calm electrodes having similar coatings had similar iron values in the slag analysis. It is believed that the globules are not an intrinsic part of the slag, but represent steel spattered backward into, and entrapped in the viscous, solidifying slag. It is also assumed that spattered slag and steel, as they leave the deposit, have the same composition as the main body of slag and steel in the pad.

Depending on the type of coating, there are seven to ten constituents which must be determined in any welding slag. It was impossible with the available facilities to perform a complete analysis of more than a very few slags owing to the complexity of the analytical procedures. A method was devised, therefore, whereby analysis of the slag for iron, manganese and sulphur or phosphorus, and in some instances silica, sufficed to permit calculation of the complete slag analysis and to permit, as well, calculation of the weights of slag and weld metal. The following actual example (Electrode 15S) illustrates the method in detail.

The composition of the coating is shown in Table 1. Of the materials in the coating, the volatile constituents consist principally of CO_2 from calcium carbonate with a small quantity of water united with the binder, sodium and potassium silicates. The volatile matter will not appear in slag or metal. The materials in the first column will react among themselves, with the materials in the second column and with the steel. However, they will not be volatilized appreciably, nor will they be reduced into the steel. Consequently, materials in the first column will appear in the same weights in the slag as in the coating. Since the materials in the first column are 61.0% of the coating, they weigh $0.610 \times 0.857 = 0.522$ gm.

Table 1—Composition of Coating of Electrode 15S, Weight per Cent

Column 1	*Column 2*	*Column 3*
TiO_2 6.5%	SiO_2 6.9%	Volatile 17.4%
CaO 20.8%	Fe 7.1%	
CaF_2 30.6%	Si 5.4%	
Al_2O_3 1.0%	Mn 2.1%	
Na_2O 1.3%	S 0.97%	
K_2O 0.8%		

NOTE: Weight of $^5/_{32}$-in. core rod per inch of length = 2.48 gm. Weight of coating per inch of length = 0.857 gm. Outside diameter of coating = 0.231 in.

The remainder of the slag consists of silica, iron oxide, manganese oxide and sulphur. Analysis showed them to be present in the slag in the following weight percentages: 3.54% FeO, 1.78% MnO, 0.42% S and 17.20% SiO_2. The sum is 22.94%. The remainder of the slag weighing 0.522 gm. amounted to 100 – 22.94 = 77.06%. Therefore the total weight of the slag is $0.522/0.7706 = 0.678$ gm.

The complete composition of the slag is calculated readily from the known quantities of the first-column constituents in the coating. The weight of the weld can be computed from the weights of iron, manganese and sulphur in slag and coating.

Weight of iron in coating: $0.071 \times 0.857 = 0.0609$ gm.

Weight of iron in slag: $\frac{0.0354}{1.29} \times 0.678 = 0.0185$ gm.

The difference is 0.0424 gm. and must have been transferred to the puddle. Similar calculations show that 0.0087 gm. Mn and 0.0192 gm. Si also were transferred to the puddle, bringing the total weight of the weld to 2.56 gm. Of the sulphur, 0.0055 gm. of the total (0.0083 gm.) in the coating did not remain in the slag. Some sulphur was transferred to the puddle, the remainder was lost by vaporization as shown in the following calculation based on a sulphur content of 0.16% in the pad.

Weight of sulphur in coating:	0.0083 gm. per inch
Weight of sulphur in core rod:	0.0006 gm. per inch
Total weight of sulphur in electrode:	0.0089 gm. per inch
Weight of sulphur in slag:	0.0028 gm. per inch
Weight of sulphur in weld:	0.0041 gm. per inch
Total weight of sulphur in slag and weld	0.0069 gm. per inch

The difference between the two sums is taken to be the amount of sulphur lost by vaporization during welding, that is, 0.0020 gm. or 24% of the sulphur in the coating. The percentage of the sulphur in the coating transferred to the weld is

$$\frac{0.0041 - 0.0006}{0.0083} = 42\%$$

Therefore, 100−42−24 = 34% of the sulphur must be in the slag, which amounts to

$$\frac{0.34 \times 0.0083}{0.678} = 0.42\% \text{ S}$$

The analyzed value also is 0.42% S. Similar calculations were made to study the iron, manganese and silicon balances.

RESULTS

Coatings Containing Phosphorus

Slag-metal relationships were studied in four types of covered electrodes containing different amounts of sulphur. Complete coating and slag compositions for a representative member of each group of electrodes are given in Table 2. The four types of electrodes correspond with the well-known AMERICAN WELDING SOCIETY types 6010, 6012, 7015 and 6020. Perhaps it is incorrect to refer to these coating compositions by type number, because within each classification of the AMERICAN WELDING SOCIETY Specification are found electrodes whose coatings, and in a few instances the core rods, vary quite widely in composition. However, it is believed that the coatings in Table 2 are fairly representative. In the absence of sulphur, these coated electrodes would conform with the intent and requirements of the AMERICAN WELDING SOCIETY Specification.

The $^5/_{32}$-in. core rods for all experimental electrodes were from the same heat of rimmed steel containing 0.13% carbon, 0.43% manganese, 0.012% phosphorus, 0.023% sulphur and a trace of silicon. Sulphur was added to the coating as iron sulphide containing 36.5% sulphur. The coatings were mixed, extruded and dried in accordance with customary procedures. The volatile values in Table 2 have been corrected for water contained in liquid binders but not wholly removed during drying. The welding current was 145 amp. for 10, 12 and 20 series; 160 amp. for 15 series. Straight polarity was used for series 12 and 20, reverse polarity for series 10 and 15. Raising the current to 220 amp. for series 12 and 20 and to 245 amp. for series 15 was found to have no effect on the composition of slag and weld metal.

Effect of Type of Coating. The results of chemical analysis and slag computations are listed in Table 3 and Fig. 6. The sulphur distribution ratio (S)/[S], where (S) and [S] are weight percentages of sulphur in slag and weld, respectively, is high for Series 15, but is low for the other three series. Evidently, the semibasic slag of Series 15 is more effective than the acid slags of the other series in combating sulphur in weld metal.

It is interesting to compare these results with the behavior of the sulphur distribution ratio toward acid and basic slags in steelmaking. Grant and Chipman[1] have shown that sulphur distribution is controlled almost exclusively by the excess base or acid count of the slag. The following molar ratios were taken as necessary for a neutral slag: 2 Base:1 SiO_2, 4 Base:1 P_2O_5, 2 Base:1 Al_2O_3 and 1 Base:1 Fe_2O_3.

The following oxides were considered to be bases: CaO, MgO and MnO. The excess base or acid count consists simply in converting the slag composition in weight percent to mols per 100 gm. of slag by dividing each weight percentage by its corresponding molecular weight.

Table 2—Coating and Slag Compositions for Four types of 5/32-in Electrodes Containing Sulfur

Type:	*6010*		*6012*		*7015*		*6020*	
Electrode No.:	*10S*		*12S*		*15S*		*20S*	
Wt. %:	*Coating*	*Slag*	*Coating*	*Slag*	*Coating*	*Slag*	*Coating*	*Slag*
Fe	3.1	...	2.8	...	7.1	...	4.2	...
FeO	1.6	15.5	1.1	11.0	...	3.5	26.6*	22.5
Mn	7.9	...	6.2	...	2.1	...	14.5	...
MnO	...	15.3	...	8.5	...	1.8	...	20.5
S	1.05	0.055	1.06	0.064	0.97	0.41	1.04	0.134
Si	...	...	...	...	5.4	...	...	...
SiO_2	27.8	37.8	19.4	18.9	6.9	17.3	38.4	47.2
MgO	6.3	8.6	3.5	3.4	...	...	0.4	0.5
TiO_2	10.9	14.9	51.7	50.3	6.5	8.2	...	...
Al_2O_3	...	...	1.5	1.5	1.0	1.3	2.3	2.8
CaF_2	...	...	...	...	30.6	38.6	...	...
CaO	...	...	2.2	2.1	20.8	26.3	1.7	2.0
Na_2O	5.7	7.8	2.6	2.5	1.3	1.6	2.5	3.1
K_2O	...	...	1.7	1.7	0.8	1.0	1.1	1.4
Volatile†	35.6	...	6.2	...	16.5	...	7.3	...
O.D.‡	0.195	...	0.193	...	0.231	...	0.220	...
Ratio§	0.110	...	0.142	...	0.258	...	0.242	...

† Volatile at the temperature of the weld puddle.
‡ O.D. = outside diameter of covering, in.
§ Ratio = $\frac{\text{weight of coating per inch}}{\text{weight of coating per inch + weight of core rod per inch}}$
* Fe_3O_4.

Table 3—Sulphur Distribution Ratios (see Fig. 6)

	Electrode No.			
	10S	*12S*	*15S*	*20S*
Wt. % sulphur in coating	1.05	1.06	0.97	1.04
Coating weight, gm. per inch	0.304	0.410	0.857	0.785
Slag weight, gm. per inch of electrode	0.224	0.421	0.678	0.640
Pad analysis				
% Mn	0.41	0.26	0.69	0.41
% Si	0.18	0.15	0.74	0.13
% S	0.122	0.159	0.160	0.214
Slag analysis, % S	0.056	0.064	0.420	0.134
% S in coating transferred to weld	75	77	42	60
% S in coating lost by vaporization	21	15	24	29
% Mn in coating transferred to weld*	−4	−19	48	−2
% Si in coating transferred to weld	...	...	42	...
Iron balance	−0.56†	−0.83†	70‡	26§
Sulphur distribution ratio = (S)/[S]	0.46	0.40	2.62	0.63

* Negative values signify loss of manganese from puddle to slag.
† Per cent of total weight of weld puddle oxidized to slag.
‡ Per cent of metallic iron in coating transferred to weld.
§ Per cent of magnetite reduced to the weld. The increase in weight of the weld compared with the weight of the core rod is 2.9%.

In applying Grant and Chipman's procedure to the welding slags, P_2O_5 was neglected. Ferric oxide was below 1% in all slags and also was neglected. NA_2O and K_2O were treated as bases. Since it was not known whether TiO_2 acted as an acid, counts were made neglecting TiO_2 and also counting TiO_2 as equivalent to 1, 2 and 3 mols of base.

The behavior of the sulphur ratio in welding toward excess base or acid is shown in Fig. 7. In plotting these results it was assumed that TiO_2 was equivalent to three mols of base. The assumption that TiO_2 acted as a strong acid improved the consistency of the results. Although it probably exists in slags combined mol for mol with available base, for example CaO:TiO_2, the TiO_2 seems to exert at least as strong an acid effect on the sulphur ratio as silica.

Figure 7 also shows that the sulphur distribution ratios for the welding slags, particularly Series 15, are higher than for the equilibrium slags studied by Grant and Chipman. The higher ratios for the welding slags probably indicate that the system weld metal-slag has not attained equilibrium. The low FeO content of the slags of Series 15 also favors high sulphur ratio. Although Grant and Chipman found fluorspar, up to 17%, neutral with respect to sulphur, it is possible that the high fluorspar content (35%) of Series 15 slags tends to raise the sulphur ratio.

In order to demonstrate the extent to which sulphur can be held in a welding slag, a $^5/_{32}$-in. electrode was prepared with the following coating: Na_2O, 27.1%; Al_2O_3, 1.0%; CaO, 1.7%; K_2O, 0.4%; MgO, 0.8%; Fe, 1.4%; SiO_2, 9.7%; S, 0.82%; and Volatile, 57.1% Coating weight = 0.460 gm./in. (0.214 in. O.D.).

The binder was organic, the Na_2O was present as bicarbonate and the coating was extruded on rimmed steel core rods of the same heat as other experimental electrodes. The coating was dried at 230° F. and the electrodes were welded at 140 amp. reverse polarity. The weld metal analyzed 0.03% carbon, 0.10% manganese, 0.03% silicon and 0.053% sulphur. Assuming 20% loss of sulphur from the coating by vaporization during welding, the slag should cont..in 1.2% sulphur. The sulphur distribution ratio on this assumption is 24, which is in the range for reducing slags in electric furnace steel practice. Fillet welds made in $^1/_2$-in. mild steel plates with this electrode exhibited no hot cracking, but had moderate internal porosity.

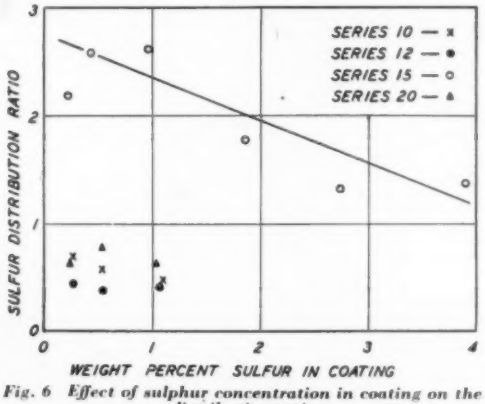


Fig. 6 Effect of sulphur concentration in coating on the distribution ratio

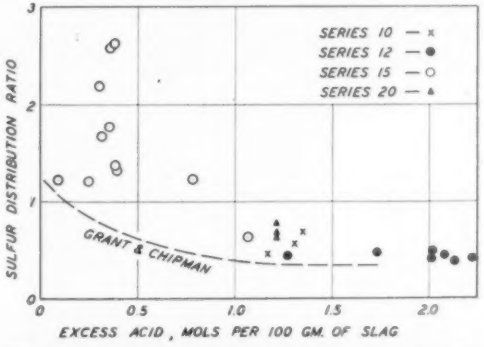


Fig. 7 Comparison of weld slag sulphur ratios with equilibrium values (dashed curve) determined by Grant and Chipman. In the acid-base count, Na_2O and K_2O are regarded as bases, while TiO_2 is regarded as acid (3 base:-1 TiO_2)

Table 4—Additions of Base to 6012 Type Coating

	Electrode No.			
	*12S1**	*12S4*	*12S5*	*12S6*
Slag composition				
Wt. %, CaO	2.0	12.4	1.6	1.5
Wt. %, MgO	3.3	2.9	22.2	2.4
Wt. %, Na_2O	2.4	2.1	2.0	10.9
Excess acid count neglecting TiO_2	0.328	0.111	−0.186	0.174
Excess acid count, $1TiO_2$:3 base	2.128	1.728	1.269	2.034
(S)/[S]	0.37	0.46	0.44	0.49

* Electrode 12S1 had lower sulphur content than Electrode 12S of Table 2, but had the same coating in all other respects.

Effect of Sulphur Concentration. Within the range 0.2–1.1% sulphur, the concentration of sulphur in the coating had no appreciable effect on the sulphur distribution ratio in the 10, 12 and 20 series. In the 15 series the sulphur content of the coatings ranged from 0.2 to 3.9%. On account of increasing difficulty in attaining equilibrium with higher sulphur contents, higher sulphur ratios were anticipated. However, the results, Fig. 6, show lower sulphur ratios at the higher sulphur contents. Perhaps a high percentage of iron sulphide in the coating reduces the effective coating thickness, and the sulphur ratio behaves as if the coating thickness had been reduced.

It is interesting to observe at this point that about the same sulphur distribution ratio is obtained if the sulphur in the slag is derived from the plate as if the sulphur is derived from the coating. A $^5/_{32}$-in. electrode having a Series 15 coating but containing no additions of sulphur was deposited as a flat bead on a high-sulphur steel plate $1^1/_2$ in. thick containing 0.24% C, 1.35% Mn, 0.011% P, 0.250% S and 0.04% Si. The welding slag contained 0.19% S while the bead analyzed 0.12% S. The sulphur distribution ratio was 1.6, which is a little lower than if the sulphur had been derived from the coating.

Effect of Coating Constituents. In an effort to raise the sulphur distribution ratio in Series 12, the basic count of the slag was raised by large additions of CaO, MgO or Na_2O to the coating, Table 4. These additions had no material effect on the sulphur ratio. Neglecting TiO_2, the electrode 12S5 had the highest excess base count (0.186) of any electrode in the four series. Here is further support for regarding TiO_2 as strongly acid. Despite the additions of base, the slags of 12S4, 5 and 6 had a high excess acid count if TiO_2 is regarded as acid.

Electrodes of Series 15 were made, Table 5, in which the effect of SiO_2 and TiO_2 on sulphur ratio was studied. While the slag with high TiO_2 (15S6) had a low sulphur ratio, the slag with no TiO_2 likewise had a low ratio, as did the slag with low SiO_2. However, with high SiO_2 (15S8) the ratio fell to 0.63, well below the value for any other electrode in Series 15. High silica content promotes transfer of sulphur to the weld in the lime-base series.

Effect of Source of Sulphur. Instead of iron sulphide, barium sulphate containing 13.7% S was used as a source of sulphur in the coatings of two electrodes. In Series 12, electrode 12S7 contained 3.8% barium sulphate and the sulphur ratio was 0.40. In Series 15 electrode 15S10 contained 6.8% barium sulphate and the sulphur ratio was 1.67. For both electrodes the sulphur distribution was practically the same as if iron sulphide had been used. As impurities in coating ingredients sulphide sulphur and sulphate sulphur are equally dangerous and in practice are held to a minimum.

Effect of Baking. All electrodes of the lime-base Series 15 were baked at 700° F. before welding to overcome porosity due to moisture in the coating. To investigate the effect of baking on sulphur ratio some electrodes of the 15S10 series containing 6.8% barium sulphate were dried at only 230° F. before welding. The slag and weld compositions were identical with those obtained with baked electrodes. There was considerable porosity in the pad made with unbaked electrodes, but none with baked electrodes. Baking temperature had no effect on sulphur distribution.

Table 5—Variations in SiO_2 and TiO_2 in 7015 Type Coatings

	Electrode No.				
	*15S3**	*15S5*	*15S6*	*15S7*	*15S8*
Slag composition					
Wt. %, SiO_2	17.0	19.3	16.0	14.2	37.1
Wt. %, TiO_2	7.9	None	29.6	8.1	5.5
Coating composition					
Wt. %, Si	5.2	5.6	4.0	2.5	3.9
Wt. %, SiO_2	7.5	7.9	7.1	7.5	28.4
Wt. %, TiO_2	6.2	None	25.9	6.6	4.7
% S in coating transferred to weld	44	48	61	62	79
% Mn in coating transferred to weld	32	47	None	11	−6
% Si in coating transferred to weld	48	42	29	25	63
% Fe in coating transferred to weld	65	71	45	40	31
Excess acid count, neglecting TiO_2	0.058	0.096	0.176	−0.053	0.865
Excess acid count, $1TiO_2$ = 3 base	0.355	0.096	1.289	0.250	1.072
(S)/[S]	1.77	1.22	1.22	1.20	0.63

* Electrode 15S3 had higher sulphur content than Electrode 15S of Table 2, but had the same coating in all other respects.

Table 6—Effect of Coating Thickness on Sulphur Distribution of a Lime-Base Type of Covered Electrode (15S1)

	Outside diameter of 5/32-in. covered electrode, in.			
Weight of coating per inch	*0.200* 0.153	*0.212* 0.195	*0.231* 0.246	*0.259* 0.330
Weight of coating + weight of core rod				
Grams of coating per inch of electrode	0.448	0.598	0.807	1.22
Grams of slag per inch of electrode	0.374	0.479	0.635	0.97
Pad analysis				
% C	0.04	0.06	0.08	0.07
% Mn	0.40	0.55	0.60	0.87
% Si	0.28	0.46	0.81	1.19
% S	0.102	0.110	0.086	0.106
Slag analysis				
Wt. %, FeO	4.9	2.8	3.3	3.4
Wt. %, MnO	2.5	2.1	1.7	1.5
Wt. %, S	0.104	0.18	0.22	0.31
Wt. %, SiO_2	19.0	18.2	16.7	17.1
% S in coating transferred to weld	96	85	46	39
% Mn in coating transferred to weld	None	30	47	58
% Si in coating transferred to weld	29	39	50	46
% Fe in coating transferred to weld	46	74	69	66
Excess acid count, neglecting TiO_2	0.131	0.094	0.046	0.063
Excess acid count, $1TiO_2$:3 base	0.425	0.400	0.358	0.372
(S)/[S]	1.02	1.64	2.58	2.94

Effect of Slag Weight. Using the 15S1 coating formula, a series of electrodes were produced having four different coating thicknesses, Table 6. The 15S1 coating is the same as 15S of Table 2 except that the sulphur content of the coating is only 0.44%. The 0.200- and 0.212-in. coatings are abnormally thin while 0.259 in. is abnormally thick. It was surprising to find that the weld pads contained nearly the same percentage of sulphur. The sulphur ratio increased without corresponding changes in basicity. The smaller the amount of slag, the more rapidly it may attain equilibrium.

Fillet welds were made in mild steel plates and were fractured for estimation of hot cracking. The 0.200- and 0.211-in. electrodes produced one or two short hot cracks, the 0.259-in. electrode produced several hot cracks, while the 0.231-in. electrode generally produced no hot cracks. The craters of fillets deposited by the thinnest coating were brittle, tended to be gassy and holes were visible in the surface of widely woven beads. Welds made with the other coating thickness were free from porosity, but were brittle.

Cracking and Porosity. The sulphur content of weld metal in practice seldom is as high as the quantities in the experimental series. Nevertheless fillet welds were made in 1/2-in. mild steel plates with each group of electrodes. Porosity and cracking were prominent and increased with sulphur content in welds made with electrodes of the 10, 12 and 20 series. No porosity was observed in fractures of Series 15S (Groups S, S1, S2, S3, S4, S9 and S10). Hot cracking was severe in 15S (0.16% S in the pad) but was absent in 15S2 (0.054% S in the pad). While no hot cracking was observed with 15S1 (0.231 O.D., 0.086% S in the pad), in unrestrained fillets, relatively slight restraint sufficed to form hot cracks. The insensitivity of 15S2 to hot cracking probably is related to its relatively high manganese content (0.60% Mn in the pad) as well as to low hydrogen. Fillets made with 15S10 (barium sulphate) with and without baking were considerably hot cracked, while the very high sulphur welds 15S3 and 15S4 deposited fillets that cracked completely from one end to the other.

Coatings Containing Phosphorus

In the same way as in the investigation of sulphur, additions of phosphorus were made to four types of coatings corresponding with 6010, 6012, 7015 and 6020, Table 7. Slag compositions and weights are similar to

Table 7—Phosphorus Distribution Ratios

*Electrode**	*Source of phosphorus*	*Coating ratio†*	*Phosphorus content of coating, %*	*(P)/[P]*	*Recovery of phosphorus‡*
10P	Ferro-phosphorus	0.133	1.48	0.20	100
10P1	Calcium phosphate	0.111	1.18	0.39	83
12P	Ferro-phosphorus	0.161	1.17	0.15	100
12P1	Calcium phosphate	0.143	1.22	0.13	88
15P	Ferro-phosphorus	0.272	1.15	0.22	97
15P1	Calcium phosphate	0.272	1.20	0.86	83
20P	Ferro-phosphorus	0.222	1.05	0.19	80
20P1	Calcium phosphate	0.222	0.82	0.22	93

* The coating formulas are the same as the corresponding coatings containing sulphur in Table 2, except that phosphorus-bearing material is substituted for sulphur.

† Coating ratio $= \dfrac{\text{weight of coating per inch of electrode}}{\text{weight of coating + weight of core rod per inch}}$

‡ Recovery $= 100 \times \dfrac{(P_{coat} + P_{core}) - (P_{slag} + P_{weld})}{P_{coat}}$; where P = grams of phosphorus per inch of electrode.

the sulphur series. Phosphorus was added to the coating mixture as ferro-phosphorus (25% P, 0.01% S, 1.0% Mn, 1.5% Si) and as tertiary calcium phosphate containing 20% P.

With ferro-phosphorus as source material the results in Table 7 show that the four types of coatings transfer a high proportion of phosphorus to the weld. There is no indication that the 7015 type of coating is different in this respect from the more acid coatings. With calcium phosphate as source material, however, the semibasic slag of the 7015 series holds 200% more phosphorus than with ferrro-phosphorus in the coating. Evidently slag reactions involving calcium phosphate are slower in 7015 slags than reactions involving ferro-phosphorus. The acid slags show less effect. The 6010 slag held 50% more phosphorus as calcium phosphate than as ferro-phosphorus. Perhaps the lime added with the P_2O_5 accounts for the increase. The 6012 and 6020 slags transferred as much phosphorus to the weld metal with calcium phosphate as with ferro-phosphorus.

Effect of Slag Weight. To determine the effect of slag weight on phosphorus distribution three series of electrodes, Table 8, were prepared using calcium phosphate as the source of phosphorus. The phosphorus ratio is a little higher for the lighter coatings. If the phosphorus ratio is used as the criterion of acidity, the 6012 slag is most acid, the 7015 slag most basic, The sulphur experiments lead to the same conclusion.

In an effort to determine whether the slags of the phosphorus series had attained equilibrium, the phosphorus ratios were compared with Winkler and Chipman's[2] results for basic slags, Fig. 8. Applying Winkler and Chipman's method to slag 15P1, the point in the left-hand corner of the graph is obtained. This point is far away from the curve numbered 46 on which it should fall. It is clear that the slag should contain less phosphorus if equilibrium were reached at 1550–1600° C. Stated in another way, the slag is more acid than it would be under equilibrium conditions with the phosphorus present. Assuming higher temperatures for the weld puddle makes matters worse.

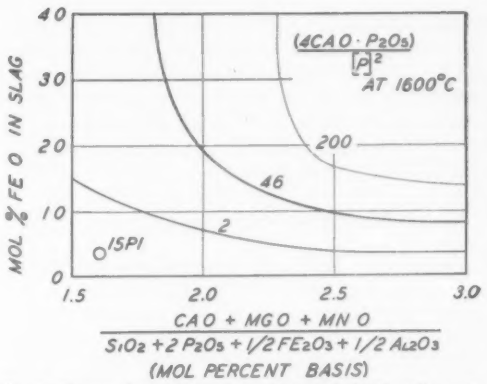


Fig. 8 Comparison of slag from Electrode 15P1 with equilibrium slags of Winkler and Chipman. The three curves show equilibrium FeO values as a function of basicity for three phosphorus distribution ratios, namely, 2, 46 and 200. The slag 15P1 should fall on the 46 curve if it were in equilibrium with the weld at 1600° C.

The low phosphorus ratios for the welding slags suggests three causes: (1) The slags are more or less acid; (2) the temperature of the weld puddle is high and (3) the welding atmosphere is reducing. The first and third causes are believed to be most likely.

Cracking and Porosity. The electrodes of the phosphorus series having normal coating weights had good weldability. There was no hot cracking or porosity. However, the welds fractured in a brittle manner under the sledge. The electrodes with coating weights lighter than normal tended to produce explosions during welding. These explosions are known to be related to the low coating weight rather than to the phosphorus content. Fillets made with the heaviest coating in Series 20 (20P1, 0.261 O.D.) were particularly concave and had severe hot cracks through the throat immediately after welding.

Although Reeve[3] reported good tensile properties for a weld containing 0.13% P, a tensile specimen of weld metal from electrode 10P had low ductility. The specimen was welded in mild steel plates in accordance with "Tentative Specifications for Iron and Steel Arc-

Table 8—Effect of Coating Thickness on Phosphorus Distribution of Three Types of 5/32-in. Electrodes

Electrode No.	*10P1*				*12P1*		*20P1*			
Outside diameter, in.	*0.180*	*0.196*	*0.212*	*0.230*	*0.195*	*0.218*	*0.201*	*0.218*	*0.240*	*0.261*
Coating ratio	0.068	0.111	0.158	0.214	0.143	0.216	0.163	0.222	0.297	0.355
Grams of coating per inch	0.178	0.308	0.465	0.677	0.413	0.686	0.480	0.707	1.04	0.37
Grams of slag per inch	0.137	0.217	0.322	0.464	0.445	0.723	0.407	0.590	0.869	1.16
Pad analysis										
% Mn	0.41	0.52	0.62	0.61	0.28	0.28	0.36	0.40	0.41	0.39
% Si	0.11	0.16	0.25	0.26	0.11	0.15	0.10	0.16	0.19	0.18
% P	0.070	0.124	0.172	0.217	0.19	0.28	0.15	0.21	0.27	0.32
Slag analysis										
Wt. %, FeO	16.5	10.5	8.9	8.0	13.6	12.3	22.1	21.4	21.6	21.5
Wt. %, MnO	13.7	13.1	12.9	13.3	8.2	7.6	21.8	21.3	21.1	21.8
Wt. %, P	0.040	0.048	0.055	0.074	0.025	0.027	0.054	0.046	0.072	0.073
% Mn in coating transferred to weld	−5	8	11	10	−14	−14	−2	0	0	1
Iron Balance*	−0.55	−0.39	−0.41	−0.51	−1.6	−2.3	25	28	28	26
(P)/[P]	0.57	0.39	0.32	0.34	0.13	0.10	0.37	0.22	0.27	0.23

* Iron balance for 10P1 and 12P1 is expressed as per cent of total weight of weld puddle oxidized to slag. Iron balance for 20P1 is expressed as per cent of magnetite in coating reduced to the weld.

Welding Electrodes" A.S.T.M. Designation A233–45T. The weld metal contained 0.08% carbon, 0.66% Mn and 0.15% phosphorus. The tensile properties were: yield point, 70,000 psi.; tensile strength, 81,000 psi.; elongation, 12% in 2 in. The phosphorus raised the tensile strength and caused the appearance of unusual, brittle fish eyes in the fracture.

OXYGEN AND CARBON

The study of sulphur and phosphorus has shown that the welding slags are acid or semibasic, and that expected reactions have proceeded a long way toward equilibrium without quite reaching it. A consideration of the other elements in the slags sheds further light on fundamentals. We will consider oxygen and carbon first because they are important factors in steel furnace reactions.

It is well known that the oxygen content of weld metal from covered electrodes other than the lime-base type is high (0.035 to 0.26% quoted in the literature) and is associated to a great extent with inclusions of silica or silicate, particularly iron and manganese silicates. In this form oxygen plays no part in carbon-oxygen reactions. For the lime-base coatings Rollason and Bishop[4] found low oxygen contents (0.009 to 0.017%) in the welds.

Lacking information on the oxygen content of the weld metals in the sulphur and phosphorus series, it is difficult to draw quantitative conclusions about the degree of oxidation of the weld metals. The carbon content of the pads made with electrodes of normal coating thickness varied between 0.08 and 0.12% in series 15 and 20 but fell to 0.05–0.09% in series 12. The 10 Series was intermediate. The low carbon content of Series 12 supports the conclusion that the weld metal in this series was exposed to the most oxidizing conditions. All weld metals in the four series tended to be abnormal in the McQuaid-Ehn test, but some specimens of series 10 and 20 were normal. The McQuaid-Ehn grain size usually was mixed partly 2–4, partly 6–7.

In the same way that the weld metal may pick up oxygen, the slag, too, may absorb it from the atmosphere in and about the arc, Table 9. The amount of oxygen absorbed by the slag was calculated from the total oxygen contents of slag and coating, excluding volatile constituents. The oxygen pick up in Series 15S1 is due principally to oxidation of silicon in the coating, whereas the pick up in Series 12P1 is due to oxidation of iron from the weld puddle. The slags of Series 10P1 absorbed little oxygen perhaps because the volatile constituents of the coating protect the weld puddle from the air. There was a small loss of oxygen from Series 20P1 due to the reduction of some of the magnetite in the coating to the weld puddle. In every series the oxygen balance was independent of the small oxygen content of the rimmed steel core rods (0.0003 gm. of oxygen per inch of $^5/_{32}$-in. rod).

The absorption of oxygen by the slags of the 10, 12 and 15 series generally was greater for the thicker coatings. It is not difficult to understand the reason for this behavior, for there are greater quantities of reducing materials to be oxidized in the heavier coatings. Although the total oxygen pickup is greater for the thicker coatings, the absorption of oxygen per gram of coating or slag is greater for the thin coatings. The slags from the lighter coatings tend to contain more FeO, which may have caused the explosions observed in welding with the lightest coatings of series 10 and 20. Heavier coatings provide more gas shielding and tend to form more reducing slags. The transfer of metal across the arc is globular for the lighter coatings which do not form a cup around the arc. As the coating thickness is increased, the coating melts less rapidly than the core rod and forms a cup around the arc. Together with this change, the transfer of metal changes to the spray type as Sjoman[5] has shown.

IRON

Closely connected with the slag's absorption or evolution of oxygen is the balance between the iron in the coating and the iron in the slag, Tables 3, 5, 6 and

Table 9—Oxygen Picked Up by Slag and Reaction Constants

Electrode No.	*Outside diameter of coating, in.*	*Weight of slag, grams per inch of electrode*	*Oxygen picked up or lost by slag*		*Mn-FeO reaction*		*Si-FeO reaction*	
			Grams of O_2 per inch of rod	*% of slag wt.*	K_{Mn}*	*Apparent reaction temp., ° C.*	K'_{Si}†	*Apparent reaction temp., ° C.*
10P1	0.180	0.137	0.0060	4.4	1.80	1670	0.033	1700
10P1	0.196	0.217	0.0058	2.7	2.43	1590	0.057	1650
10P1	0.212	0.322	0.0080	2.5	2.36	1600	0.049	1670
10P1	0.230	0.464	0.0097	2.1	2.76	1560	0.061	1650
12P1	0.198	0.445	0.0145	3.3	2.24	1610	0.049	1670
12P1	0.218	0.723	0.0201	2.8	2.24	1610	0.044	1680
15S1	0.200	0.374	0.027	7.2	1.25	1760	0.149	1570
15S1	0.212	0.479	0.028	5.9	1.39	1740	0.278	1520
15S1	0.231	0.635	0.033	5.1	0.86	1860	0.111	1600
15S1	0.259	0.969	0.052	5.3	0.50	2030	0.073	1640
20P1	0.201	0.407	0	0	2.78	1560	0.0204	1740
20P1	0.218	0.590	−0.0025	−0.42	2.48	1580	0.0137	1800
20P1	0.240	0.869	−0.0043	−0.49	2.43	1590	0.0112	1810
20P1	0.261	1.16	−0.0030	−0.26	2.64	1570	0.0121	1800

* $K_{Mn} = (MnO)/(FeO)[Mn]$. ( ), mol fraction in slag; [ ], wt. % in metal.
† $K'_{Si} = 1/[Si](FeO)^2$. ( ) and [ ] = wt. %.

8. All iron in the coatings of Series 12 was oxidized along with 1 to 2% of the weight of the core rod. Likewise for Series 10 all iron in the coating was oxidized together with ½% of the core rod regardless of coating thickness. On the other hand, all metallic iron in the 20 Series was transferred to the puddle. Furthermore, 25% of the magnetite in the coatings of Series 20 was reduced to iron and was transferred to the weld puddle, regardless of coating thickness.

In Series 15 about 70% of the metallic iron in the coating was transferred to the puddle with a few exceptions. The lightly coated electrode 1581 (0.200 in. O.D.) transferred only 46% of the iron in the coating to the puddle. The thin coating seems to offer inadequate protection against admixture of air in the atmosphere surrounding the weld puddle. The coatings with high TiO_2 (1586) and high SiO_2 (1588) also slagged a considerable proportion of the metallic iron in the coating. The coating with low silicon (1587) behaved in accordance with expectations in permitting greater oxidation of iron than the coatings with higher percentages of this powerful deoxidizer.

With the exception of the slag from the coating high in Na_2O described in the section on sulphur, less than 1% of ferric oxide was found in any of the welding slags. The high silica content of the slags provides the explanation. A chart prepared by Whiteley[6] from an investigation of ferric oxide in slags of varying lime and silica contents shows that the percentage of ferric oxide in a slag follows the lime or silica content. High silica contents were associated with low ferric oxide.

MANGANESE

The manganese content of the core rod was barely maintained in the 6010 and 6020 series of weld metals, Tables 3, 5, 6 and 8, and was not maintained in the 6012 series. It is comparatively difficult to transfer large amounts of manganese from coatings of series 10 and 20 without creating porosity. The loss of manganese from the core rod of Series 12 is due to oxidation. Once again we find that the weld metal of Series 12 is most oxidixed. The transfer of manganese from coating to weld in the lime-base Series 15 was aided by the ferro-silicon in the coating.

In the 158 Series the manganese tended to revert to the slag as the sulphur increased. High TiO_2 (1586) or high SiO_2 (1588) caused all manganese in the coating to remain as MnO in the slag, owing to the higher acidity. Although the manganese content of 1584 weld metal (0.53% Mn, 0.44% S) is present almost entirely as manganese sulphide, the action of the manganese in slag-metal reactions is not altered.

Variation in slag weight had no effect on the manganese content of the weld metal in series 12 and 20. There was a small increase in the manganese content of the welds in the 10P1 series, Table 8, as the coating thickness was increased. In the 1581 series the percentage of the manganese in the coating transferred to the weld increased from less than 5% at 0.200 in. O.D. to about 50% at 0.259 in. O.D. Increase in coating thickness accentuated the reducing character of the welding environment perhaps by increasing the quantity of ferrosilicon and manganese in the coating.

The reaction that appears to govern the manganese contents of slag and weld metal is

$$(FeO) + [Mn] = (MnO) + [Fe]$$

The equilibrium constant for the reaction is

$$K_{Mn} = \frac{(MnO)}{(FeO)\,[Mn]}$$

$$\text{Log } K_{Mn} = \frac{6600}{T} - 3.16 \qquad \text{(Fig. 9)}$$

In the equation for K_{Mn} the manganese content of the weld metal is expressed as weight percentage. The FeO and MnO contents of the slag are expressed as mol fractions.

The equations represent basic steelmaking conditions but do not apply very well to acid steelmaking slags. Nevertheless, the reaction constants calculated for series 10, 12 and 20, Table 9, are in good agreement, and correspond with an equilibrium temperature of 1600° C. While these calculations are far from proof that the system—weld metal-slag—was in equilibrium or that the temperature of the weld metal reached or exceeded 1600° C., they lend support to the belief that the FeO-MnO reaction is important.

The values of K_{Mn} for Series 15 are fairly constant but correspond with an equilibrium temperature of 1900° C. Conditions that favored the slagging of iron, manganese and silicon such as high SiO_2 or low metallic silicon in the coating and light coating weight lowered the calculated equilibrium temperature.

A close relationship has been established by McCance[7] between the ratio of MnO to FeO in acid and basic steelmaking slags and the manganese content of the steel. The MnO/FeO ratios for the welding slags were found to depart widely from this relationship. It was impossible to use the graph developed by Mc-

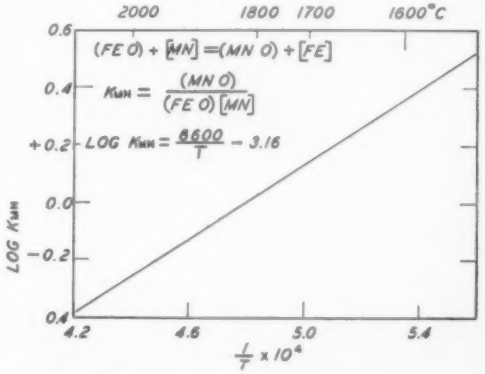


Fig. 9 Plot of the manganese-iron oxide reaction constant for comparison with weld slag analyses

Cance to estimate the relative acidity of the welding slags.

Another reaction that was studied in relation to the welding slags is the reduction of MnO by silicon.

$$2[Mn] + (SiO_2) = 2(MnO) + [Si]$$

$$K_{MnSi} = \frac{Mn^2}{[Si]\,(MnO)^2}$$

$$\text{Log } K_{MnSi} = \frac{3177}{T} - 3.757$$

All quantities in the two equations are expressed as weight percentages.

The manganese-silicon distribution applies particularly to acid process slags. At equilibrium K_{MnSi} has the values 0.00107 at 1500° C. and 0.00087 at 1600° C. Values of K_{MnSi} computed for the welding slags of the 10, 12, 15 and 20 series are approximately 0.008, 0.010, 0.15 and 0.002, respectively. These are far from equilibrium at possible temperatures and correspond with impossibly low equilibrium temperatures. The failure of the manganese-silicon distribution to represent welding conditions seems to be related to the high total silicon content of the weld metals or the low MnO values of the slags, compared with the manganese content of the weld. The results for Series 20 approach the manganese-silicon distribution most closely because these slags contain little lime and no TiO_2.

The K_{MnSi} ratio is closely related to the ratio [Mn]/(MnO) used by Bischof,[8] who showed that the more basic the welding slag, the higher is the value of the ratio. Results for the sulphur and phosphorus series confirm Bischof's conclusion in general. The [Mn]/(MnO) ratio was 0.02 to 0.06 for the acid series 10, 12 and 20, but rose to 0.2 to 0.4 for the semibasic Series 15.

SILICON

Although ferro-manganese is present as a major constituent in series 10, 12 and 20, silicon in metallic form is absent. Yet the weld metals of these series contained 0.10–0.15% silicon. Some of the silicon, as Sloman[9] and co-workers showed, is in inclusions of silica and silicate, but a little silicon is reduced from the slag. The amount of silicon transferred from coating to weld was small and was neglected, except in Series 15. In this series, Tables 3, 5 and 6, about half of the metallic silicon in the coating was transferred to the weld metal. Lowering the percentage of metallic silicon in the coating lowered the percentage transferred, while raising the SiO_2 content of the coating raised the percentage of silicon transferred.

As the coating weight was increased, there was an increase in the silicon content of the weld metal in Series 15, at least up to a coating diameter of 0.231 in. The silicon recovery was no higher in the 0.259 in. coating than in the 0.231 in. coating. As the coating weight increased in the 10, 12 and 20 series there also was an increase in the silicon content of the weld metal. It is impossible to state whether the increase represents an increase in metallic silicon or an increase in inclusion content.

Microscopic examination of the welds of the four phosphorus series revealed the least inclusions in the 15P series, Fig. 10, which is in agreement with its presumably low oxygen content. Most of the inclusions in the phosphorus series were glassy, indicative of high SiO_2, and showed the polarizing cross described by Hoyt.[10] A few duplex inclusions were found in the 12 series, Fig. 11. There was no opportunity to analyze the inclusions, but on the basis of research performed at the National Physical Laboratory, England,

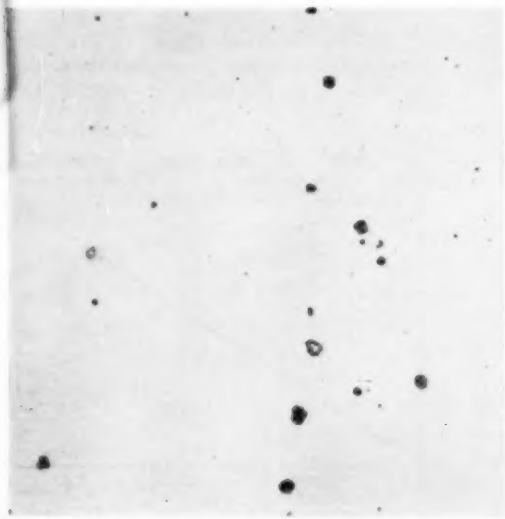


Fig. 10 (a). Inclusions in weld metal deposited by 1/8-in. Electrode 15P. Unetched. × 1250

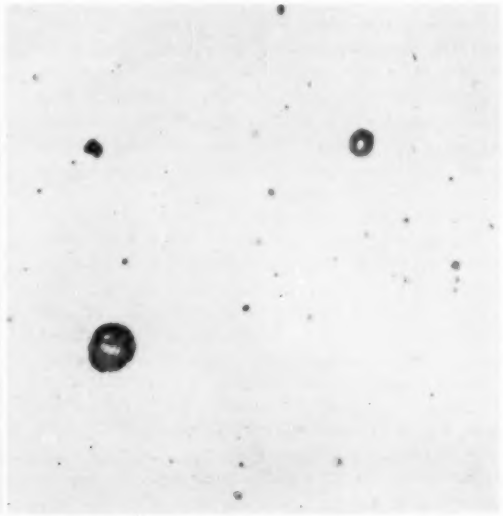


Fig. 10 (b). Inclusions in weld metal deposited by 1/8-in. Electrode 12P. Unetched. × 1250

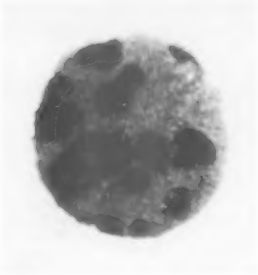


Fig. 11 Large inclusion with duplex structure in weld metal deposited by 1/4-in. Electrode 12P. Unetched. ×1500

they probably consist principally of silicates of iron and manganese. If so, the inclusions arise from reactions within the weld and are not trapped particles of slag.

The reaction that silicon undergoes in acid slags is

$$[Si] + 2(FeO) = 2[Fe] + (SiO_2)$$

The equilibrium constant for this reaction is

$$K_{Si} = \frac{(SiO_2)}{[Si](FeO)^2}$$

Owing to lack of fundamental data, it is difficult to determine the variation of K_{Si} with temperature.

$$\text{Log } K_{Si} = \frac{13{,}400}{T} - 4.06$$

The equation resulted in the following equilibrium temperatures: 6010 Series, 1700 to 1980° C.; 6012 Series, 1900 to 2000° C.; 7015 Series, 1520 to 1640° C.; 6020 Series, 1740 to 1810° C.

Instead of K_{Si}, use was made of another constant based on the assumption that the activity of silica in the slag is unity[11]

$$K'_S = \frac{1}{[Si](FeO)^2}$$

$$\text{Log } K'_{Si} = \frac{19{,}057}{T} - 11.10$$

As shown in Table 9 and Fig. 12, the values of K'_{Si} are fairly consistent and lead to the following equilibrium temperatures: 6010 Series, 1600 to 1700° C.; 6012 Series, 1670 to 1680° C.; 7015 Series, 1520 to 1640° C.; 6020 Series, 1740 to 1810° C.

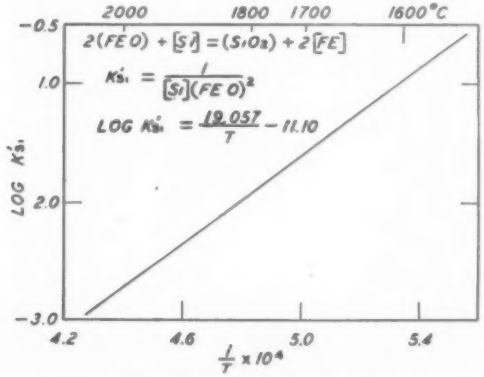


Fig. 12 Plot of the silicon-iron oxide reaction constant for comparison with weld slag analyses

These temperatures are a little higher than for K_{Mn} in the 10, 12 and 20 series, but lower than for K_{Mn} in the 15 Series. The FeO content of the welding slags seems to be not too far out of equilibrium with the manganese and silicon contents of the weld metal in the four series of electrodes.

SUMMARY

It is now time to gather together and review the information we have gained about sulphur and phosphorus in covered electrodes and about the fundamental reactions governing the production of weld metal. The following conclusions apply only to the particular coating compositions of this paper, and should not be applied indiscriminately to electrode coatings in general.

1. The sulphur distribution was not far from equilibrium and depended on slag basicity. Not only did the oxides of calcium, magnesium and manganese act as bases, but the oxide of sodium as well. There is good reason to regard TiO_2 as an acid constituent of these electrode coatings.

2. The phosphorus distribution did not reach equilibrium. Phosphorus was transferred to the weld metal to a greater extent than sulphur for a given type of coating.

3. The major slag reactions governing the manganese and silicon contents of the weld metal were between these elements and iron oxide. The reactions appeared to reach substantial equilibrium, which came about through appropriate adjustment of coating weight and coating composition. In 6010, 6012 and 6020 series enough manganese was added to the coating to provide a slag in equilibrium with steel containing 0.25 to 0.45% manganese. Control over hydrogen porosity may be exercised by the relatively high oxygen content of the weld metal. There was sufficient manganese in the 6020 Series to reduce a portion of the magnetite in the coating to iron. Organic matter in the coating which carbonized at the tip of the electrode during welding, may have aided the reduction. Of these three series of coatings and slags, all were acid, the 6012 slag being most acid.

The lime coating of the 7015 Series provided a large amount of semibasic slag with very little iron oxide for reaction with carbon in the weld puddle. The low concentration of hydrogen in coating and arc atmosphere prevented hydorgen porosity in the deoxidized weld puddle during freezing. Enough iron was oxidized to balance the oxidation of manganese and silicon. Beyond its effect on slag fluidity, the large percentage of fluorspar in the coating appeared to play a neutral part.

In summarizing the results it will be observed that we have accounted for the part taken in weld metal reactions by the important constituents of the electrode.

It should not be imagined, however, that this is all there is to the production of weld metal from covered electrodes. One of the most important constituents of a coating is water and it scarcely has been mentioned in this discussion. It, with many other problems, must await consideration by researchers, who, following the lead of Dr. Adams, are willing both to acknowledge problems and to attack them.

ACKNOWLEDGMENTS

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Some Metallurgical Aspects of Austenitic Welds

Metallurgical characteristics of chromium-nickel welds. How to avoid crater, root and intergranular cracking. Effect of cold working

by C. T. Gayley

ASIDE from the welding of stainless steels and other austenitic chromium-nickel alloys with electrodes of the same composition, these electrodes have been found useful and important in many applications because the deposited weld metal possesses high-tensile strength, high ductility, high impact resistance and notch toughness at low temperatures. The electrodes of the A.I.S.I. types 307, 308 and 310 alloys have been particularly useful in welding air-hardenable steels.

The object of the present paper is to discuss some of the metallurgical characteristics of austenitic welds of the high-chromium, high-nickel type that should be given consideration in certain applications. The principal characteristics that will be considered are: tendency to crater cracking, root cracking, intergranular cracking, lamellar structure of the weld metal, directional properties and the effect of cold working and recrystallization. The first three of these are very closely related and are due to the hot shortness of some of these alloys.

CRATER CRACKS

The first characteristic of the austenitic weld metals that will be discussed is the tendency to crater cracking. This deficiency is most troublesome when depositing the root pass of a highly restrained joint of the double vee type. Certain techniques for breaking the arc as described in the following paragraph have been tried, and it was found that the use of one technique in particular went a long way in overcoming this defect.

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Fig. 1 Techniques for breaking the arc

At *A*, Fig. 1, the arc was broken by drawing the electrode away in the direction normal to the plate. The resulting crater is wide and concave, the metal is thin and invariably the crater has one or more cracks. At *B*, the arc was shortened, the crater filled and then the arc was drawn slowly forward along one side of the scarf and finally broken about $^1/_2$ in. from the nominal end of the weld deposit. The technique fills the crater, gives the last metal to solidify a convex surface and retards the cooling rate of both the upper and lower surfaces. Properly done, no crater crack develops. At *C* the deposit was thickened by an oval motion of the electrode, making a wide convex surface, and the cooling rate was further retarded by twice making and breaking the arc. A crater crack is generally avoided.

It would seem that in order to prevent crater cracks the metal should be thickened at the crater, brought to a convex surface and the cooling rate retarded. Depositing a heavy first pass aids in obtaining the favorable conditions in that the heavier deposit is slower to cool. Making an extra heavy deposit at the crater, as in Technique C, making the surface convex, and twice making and breaking the arc, quite nearly approaches the favorable conditions. However, this technique is troublesome in the vertical and overhead positions. Furthermore, while the technique prevents a crater crack, a root crack beneath the crater often occurs, an even more serious defect.

Technique B has been applied most successfully. Its principal merit seems to be the slower cooling rate obtained for both the top and bottom sides of the weld metal, by shortening the arc and drawing it straight forward near the bottom of the groove, but on one scarf.

Although the technique prevents crater cracks, some chipping is necessary to prepare the end of the weld for making a satisfactory start with the next electrode. When the surface left by Technique B is prepared for the new start, weld metal without defect is assured; whereas, when a crater crack occurs, it is difficult to determine when it is completely removed by chipping. Little trouble with crater cracking is experienced after the first pass has been made.

ROOT CRACKS

Root cracks in austenitic welds are also most frequent in a highly restrained weld of the double vee type. Whenever the root layer of such a joint is deposited too thin by rapid progression of the arc, and with a high welding current, a root crack may be expected. A thick deposit for the first layer of such a joint is the most effective way of reducing root cracking. By the use of a medium welding current, and a heavy root pass, root cracks in the flat and vertical positions are readily eliminated.

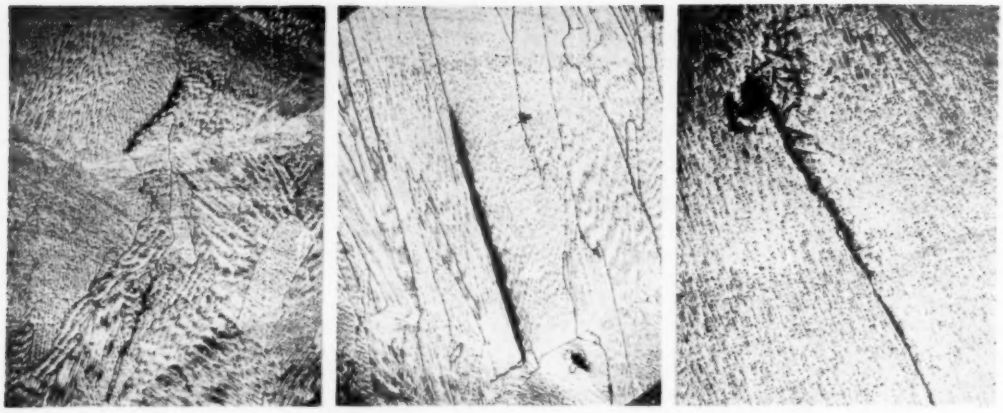
The overhead position gives the most trouble. In the flat and vertical positions the molten weld metal sags through the root opening due to the pull of gravity, and therefore solidifies with a convex surface. In the overhead position where gravity is opposed, the metal generally solidifies with a concave root surface. Furthermore, it is more difficult to deposit a heavy layer in the overhead position, and thus decrease the cooling rate, as well as bring the base metal to a higher temperature for the next pass. However, with a welding current near the low side, an electrode not too large, and a little practice in depositing a heavy first layer, root cracks in the overhead position may be eliminated.

Fig. 2 Weld in 60-lb. high yield steel. 10% acid ferric chloride etch. 2 ×

INTERGRANULAR CRACKS

The strong tendency of austenitic weld metal of the high-chromium, high-nickel type to form large columnar grains is well known. A typical example of the orientation of these grains is shown in Fig. 2. This macrograph is of a transverse section of a single U-joint in $1^1/_2$-in. plate. It is to be noted that a long axis of these grains is always approximately at right angles to the freezing or isothermal lines; that is, parallel to the direction of most rapid heat transfer by conduction. It is also to be noted that the grains are not confined to a single layer of weld metal, but may extend through several of the superimposed and individually deposited layers.

When austenitic weld metal is examined at higher magnifications, it is found that there are occasional cracks or voids along the grain boundaries. Typical examples of such cracks are shown in Fig. 3. These cracks may vary from a few thousandths to several hundredths of an inch long. It is difficult to wash the specimens sufficiently after etching to prevent the



A B C

Fig. 3 Micro-fissures in 25–20 weld metal. 10% acid ferric chloride etch. 100 × (reduced 1/3 in reproduction)

cracks from weeping and causing a stain on the surface of the specimen, or leaving crystals of ferric chloride on evaporating, as in Fig. 3 (*C*). This indicates the cracks have considerable depth and definitely are not slag dykes.

Examination of a cross section containing many large cracks of this type, as in Fig. 4, shows that they almost invariably occur along the grain boundaries and roughly parallel to a long axis of the grain. They occur at right angles to the isothermal lines. Figure 5 is a view of the top surface of the same weld after having been cleaned and etched. The photograph shows very clearly that the cracks occur exclusively at right angles to the isothermal or freezing lines and parallel to a long axis of the grains. Mentally combining the two figures will show that the large grains are not columnar, as they are so often described, but are quite flat. The structure may be described as lamellar. The lamellae are oriented quite consistently at right angles to the isothermal lines, and the cracks occur along the sides of the lamellae.

Intergranular cracks, as large as those shown in Fig. 5, may be seen as they appear, if the solidifying weld metal is carefully watched through the dark window of a welder's helmet. They occur during or shortly after the weld metal solidifies and while it is still at a high temperature. This, the fact that they occur at right angles to the isothermal lines, and are intergranular, stamp them quite definitely as cracks occurring above the

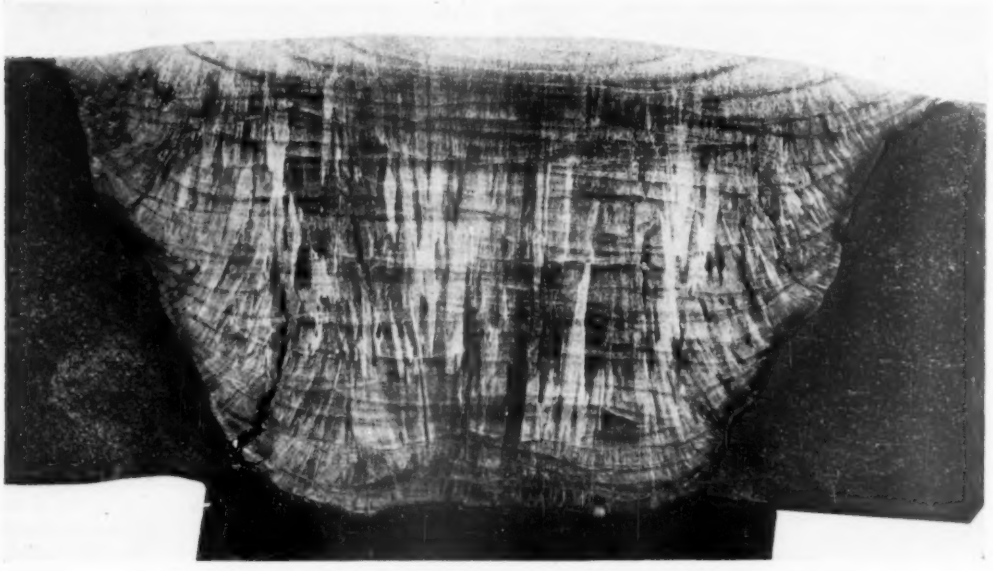


Fig. 4 Type 310 weld metal in 30-lb. plate. 10% acid ferric chloride etch. 4 ×

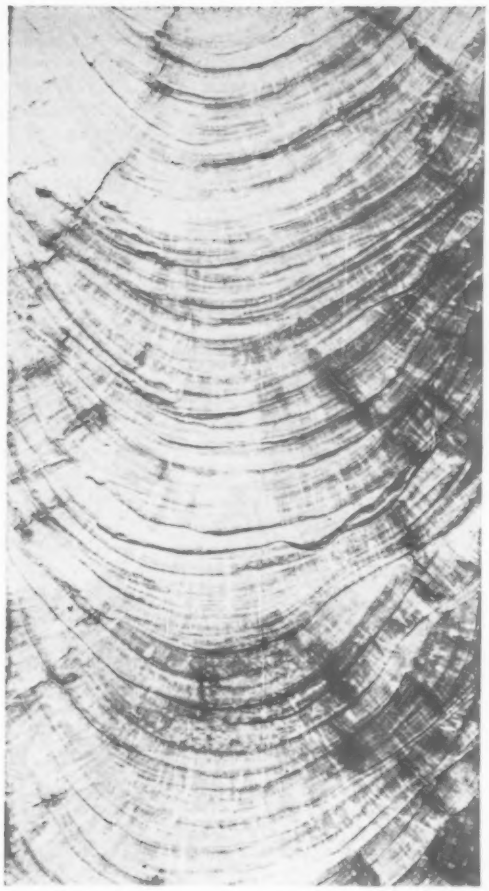


Fig. 5 Type 310 weld metal, top surface. 10% acid ferric chloride etch. 4 ×

equicohesive temperature, and apparently due to hot shortness.

An unbroken series of intergranular cracks may be observed from the largest to the most minute ones discovered by the microscope. So that while the intergranular cracks of microscopic size may not be seen in the act of forming at a high temperature, nevertheless they all seem to be of the same general nature, and it is inferred that the microscopic ones also occur above the equicohesive temperature and are due to hot shortness.

There is a great deal of evidence indicating that some heats of the Type 310 austenitic steel are more susceptible to intergraular cracking than others. Intergranular cracking also varies with the type of electrode. In general, the lime-type electrodes containing no titania deposit weld metals less susceptible to this type of defect than do titania type electrodes.[1, 2]

Sulphur, silicon and phosphorus have been shown to induce micro- and macro-fissuring when too large an amount is present singly or in total.[1, 2] High silicon has been shown to be harmful and in 25% Cr – 20% Ni weld deposits the harmful effect has been attributed to the formation of silicate films surrounding the austenitic grains.[3]

More recently, small amounts of titanium have been under suspicion as at least contributing to micro-fissuring.[4] It was found that in titania-type electrodes having 20% titania and 5% ferro-silicon in the coverings a reduction in titania occurs with the recovery of titanium in the weld metal. The amount of titanium appearing in the weld metal varied from 0.016 to 0.024%. However, this small amount was apparently sufficient to induce hot-short cracking.

A small reduction of titania, perhaps overlooked, may be the answer to the question raised by Campbell and Thomas,[1] namely, "Why does the lime-type 25–20 electrode perform so much better than the titania type?" with respect to weld metal cracking and lower tensile properties of the weld deposits.

Severe intergranular cracking seriously affects the tensile properties of the weld metal, as may be seen by examining the results of tensile test of Type 310 weld deposits given in Table 1.

Table 1.—Tensile Properties of Longitudinal All-Weld-Metal Specimens Taken from Butt Vee-Joints and Number of Intergranular Cracks (Standard 0.505-in. Specimens)

Electrode		Intergranular cracks per square Inch	Tensile strength, Psi.	% Elongation, in 2 in.
Brand No.	Diam., in.			
1	5/32	None	89,700	44
2	5/32	None	96,500	26
1	3/16	None	91,000	50
2	3/16	None	95,500	28
3	5/32	31	78,500	10
3	3/16	27	66,000	6.5

Further, the orientation of the cracks and the orientation of the grains and grain boundaries may well be a factor in giving weld deposits of this type directional properties. A comparison of the tensile properties of Type 310 weld deposits in heat-treated, high-yield air-hardenable steel, in the longitudinal and transverse directions, is given in Table 2.

Table 2—Tensile Properties of Longitudinal and Transverse Specimens Taken from Butt Vee-Joints (Standard 0.505 in specimens)

Longitudinal specimens		Transverse specimens	
Tensile strength Psi.	% Elongation in 2 in.	Tensile strength Psi.	% Elongation in. 1-in. weld metal
87,500	32	87,500	16
87,500	32	89,000	16
87,500	30	79,000	6
86,500	36	85,500	10
87,500	33	89,500	19
87,200	38	91,200	21
87,500	31	92,200	17
86,500	32	89,700	16
88,000	39	92,000	15
86,000	38	94,500	15
86,500	34	91,000	21
86,500	35	95,000	14

Fig. 6 Macrograph of fractured end of Type 310 weld metal tensile specimen. 5 ×

The above longitudinal specimens were all weld metal and the transverse specimens about 1-in. weld metal in the center and the rest of the specimen base metal. It will be noted that the elongation of the longitudinal specimens is about twice that of the transverse specimens. If the elongation of the longitudinal, all-weld-metal specimens had been measured over a 1-in. gage length across the fracture, as was done for the transverse specimens, the elongation in the longitudinal specimens would have been even greater than that indicated by the figures in the table.

Some of the difference in the elongation of the transverse specimens over that of the longitudinal specimens may be attributed to the restraining effect of the parent metal at each end of the gage length, but this effect is not considered to be of the magnitude indicated.

The other thought is that the orientation of the lamellar grains, and the intergranular cracks, may well be a contributing, if not the greater, factor.

It has already been pointed out that the large grains of the austenitic welds are quite consistently oriented at right angles to the isothermal lines and that the cracks occur along the sides of the lamellae. When a longitudinal tensile specimen is taken from the central area of a butt vee-joint it may readily be determined, by referring to Figs. 4 and 5, that any intergranular cracks present in the specimen, and the lamellar grains themselves, will be roughly parallel to the longitudinal axis of the specimen. In a contrary manner, many of the intergranular cracks and lamellar grains will be transverse to the long axis of the transverse specimens.

It therefore seems reasonable to conclude that since the cracks occur in planes roughly parallel to the long axis of the longitudinal tensile specimens, they have little effect on the tensile strength and elongation in this direction. Each section of metal, although partly separated by a crack, will behave somewhat as an individual and perfect tensile specimen, like the strands of a wire cable. The cracks and lamellar grains being roughly at right angles, or at shearing angles, to the long axis of the transverse specimens, it is to be anticipated that elongation and reduction in area would be greatly hampered. It seems probable then that the directional properties of the weld metal are derived from the mechanical effects of the cracks combined with the more frequent occurrence of grain boundaries in the one direction, rather than with any directional properties of the atomic lattice.

The grain boundaries of the lamellar grains are themselves points of weakness under certain conditions. The fractured end of a longitudinal austenitic all weld metal tensile specimen, Fig. 6, shows how prone the weld metal is to cleave along the lamellar grain boundaries, the grains themselves failing in shear between the boundaries, producing the serrated appearance.

COLD WORKING

The large lamellar grains of austenitic weld metal may be prevented from extending through several layers, as in Fig. 2, by cold working and recrystallization, as in Fig. 7. The areas of recrystallization are especially apparent below the fifth to tenth layers deposited. The cold working is accomplished by peening and the recrystallization is brought about by the heat applied in the deposition of the subsequent layer. It follows that the cold working by peening must extend below the normal depth of penetration by the arc during the process of depositing the next layer. The peening of the first few layers of the weld shown in Fig. 7 was insufficient to accomplish the desired result. The grain size of a recrystallized area is shown in Fig. 8 and the grain size near one of these areas is shown in Fig. 9. A

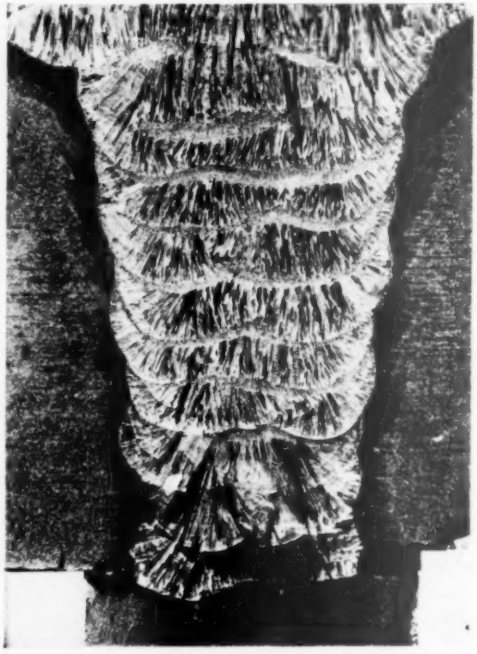


Fig. 7 Macrograph of type 310 weld metal deposited in 2-in. plate peened after each pass. 2 ×

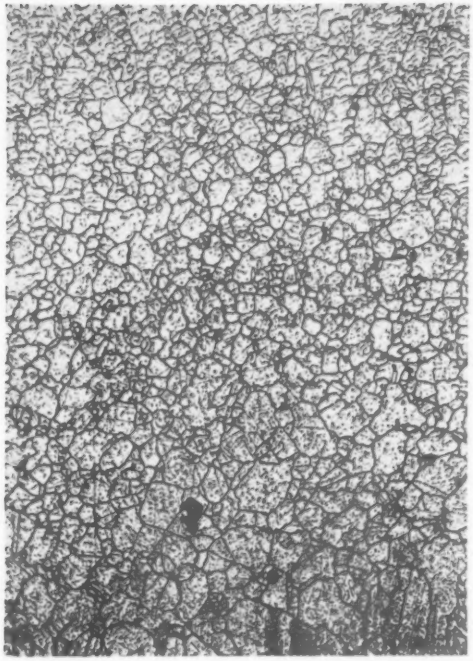


Fig. 8 Type 310 weld metal cold worked by peening and caused to recrystallize by heat of subsequent pass. 10% acid ferric chloride etch. 100 ×

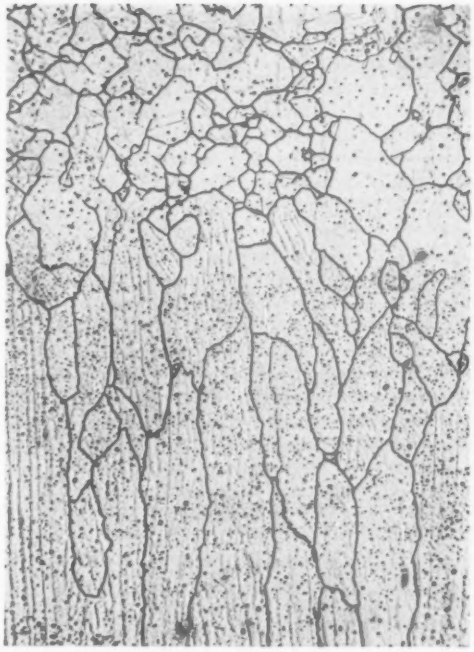


Fig. 9 Type 310 weld metal adjacent to area shown in Fig. 8. 10% acid ferric chloride etch. 100 ×

single large grain of Fig. 2 nearly covers the field of the microscope at the same magnification.

As a result of the cold working and recrystallization of the austenitic weld metal, the tensile strength is increased and the elongation decreased. Some idea of the relationship between peening time, shape of tool, size of hammer and tensile properties of longitudinal all-weld-metal specimens is revealed by a study of Table 3. These results were obtained with standard 0.505-in. diam. tensile specimens from single vee butt welds in 1-in. plate.

Examination of this table indicates that the shape of the tool has less to do with sufficient peening than the size of the hammer. The flat tool, however, seems a little less effective than the round nosed tools. A tool with a crescent shaped end about 1/4 in. wide and having a curvature of 1/2 to 3/4 in. diam. was also found very effective, and has the advantage that it can be used close up to the edge of the weld. It will be noted that the blow of the No. 80 pneumatic riveting hammer using about ninety pounds' air pressure, followed by recrystallization, was much more effective in increasing the tensile

Table 3—Effect of Peening and Recrystallization on the Tensile Properties of Austenitic Weld Metal

Size and shape of tool	*Property determined*	*Peening time per square inch of weld metal — 5 sec.*	*10 sec.*	*30 sec.*	*1 min.*	*2 min.*
Peened with a No. 2 pneumatic chipping hammer						
1/4-in. diam. ball end tool	Tensile strength, elongation	92,200 39.5%	94,500 30%	96,500 28%	96,500 33%	104,500 20%
1/2-in. diam. ball end tool	Tensile strength, elongation	... ...	94,000 36.5%	101,500 25%	103,500 22.5%	104,500 30.5%
1-in. diam. ball end tool	Tensile strength, elongation	... ...	94,500 35%	95,500 32%	104,000 22.5%	100,000 32%
1/4 x 1/2-in. flat end tool	Tensile strength, elongation	... ...	92,000 41%	93,500 33.5%	94,500 33.5%	99,000 32%
Peened with a No. 80 pneumatic riveting hammer						
1/4-in. diam. ball end tool	Tensile strength, elongation	95,500 31%	102,500 31.5%	108,000 20%	... ...	... ...
1/2-in. diam. ball end tool	Tensile strength, elongation	98,000 31%	100,500 28.5%	107,000 15%	... ...	... ...
1-in. diam. ball end tool	Tensile strength, elongation	95,500 33%	101,000 31%	110,000 28%	... ...	... ...
1/4 x 1/2-in. flat end tool	Tensile strength, elongation	94,000 40.5%	96,500 35.5%	110,500 31%	... ...	... ...

strength than was the blow of the No. 2 sealing hammer. A practical combination for peening this type of weld metal would seem to be to peen each pass, using a No. 80 riveting hammer, a crescent shaped tool about 1/4 in. wide with a 1/2-in. diam. curvature, and a peening time of 10 sec. per square inch of weld deposit.

While cold working and recrystallization increases the tensile strength of 25Cr–20–Ni austenitic weld metal, this procedure does not eliminate all directional tensile properties. The evidence for this is given in Table 4, where each figure represents the average of twenty-four tensile results from eight large welds each pass of which was peened before the deposition of the subsequent metal. All results were obtained from standard 0.505-in. diam. tensile specimens. The longitudinal and the normal specimens were all weld metal. The transverse specimens contained an average of about 1 in. of weld metal. The elongation given for the transverse specimens was the elongation in the weld metal.

Table 4—Directional Properties of Austenitic Weld Metal

	—Direction of long axis of specimen—		
	Longitudinal	*Transverse*	*Normal*
Yield strength, psi.	78,200	75,600	65,100
Tensile strength, psi.	98,800	89,600	90,300
Elongation, per cent.	22.5	11.9	17.1

SUMMARY

Crater cracks in austenitic weld metal may be prevented by filling the crater, producing a convex surface, drawing the arc forward along the parent metal and then breaking. Root cracks may be eliminated by putting in a heavy first pass with welding current toward the low side.

The large grains of the austenitic weld metal are lamellar. The grain boundaries are points of weakness, especially at higher temperatures. Some heats of austenitic steel, from which the core wire is made, are subject to intergranular cracking. They appear to be "hot-short."

Severe intergranular cracking seriously affects the strength of the weld.

Austenitic weld metal shows directional tensile properties.

Sufficient cold working by peening followed by recrystallization increases the tensile strength of the weld metal about 20,000 psi., but decreases the elongation. The grains are also greatly reduced in size, and become more nearly equiaxed.

The opinions and assertions contained herein are the private ones of the writer and are not to be construed as official or reflecting the views of the Navy Department or the naval service at large.

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The Economies of Hardfacing

Advantages of hardfacing are reviewed and an analysis of the problem leading to the correct selection of the proper hardfacing rod are indicated. Design and cost figures are covered

by J. J. Barry and Albert Muller

INTRODUCTION

HARDFACING of parts subject to wear is a comparatively recent development dating back hardly more than 25 years. With the advent of the development of welding, restoration of surface dimensions with mild steel was attempted. This provided increased service life but was not entirely satisfactory. Naturally, this led to experiments with alloys which produced hard metals or hardfacing alloys. The petroleum and construction industries were among the first to make use of this process. Hard metals were applied to oil-field drilling tools and certain types of excavating equipment to resist abrasion and to maintain a cutting edge. The successes achieved soon caused hardfacing to be utilized in other fields, and unusual growth of the process followed. Today, hard facing has become one of the most important maintenance factors in industry.

Hardfacing is a process in which an alloy is deposited on a metal part, thereby forming a protective surface which resists abrasion, impact, corrosion or heat, or any combination of these wear factors. Wear is an ever-present phenomenon since parts are always subject to chemically corrosive and physically erosive influences. In its broader aspect, hardfacing comprehends the maintenance of surface dimensions against the effects of wear.

The primary function of hardfacing is to prolong the life and increase the operating efficiency of the part involved. Not only may the worn metal in used parts be replaced, but wear on the surface of new parts may be minimized by an application of a thin layer of a hard metal which prolongs the life of the surface so protected.

Several economies are apparent with increased service life:

1. Hardfacing maintains surface dimensions against wear, thereby increasing efficiency and reducing power costs. When a part begins to wear its effectiveness as a producing unit decreases. In order to compensate for this decrease in efficiency and output, more power is used to operate the machine in order to maintain satisfactory production.
2. Hardfacing prolongs the service life of a part, thereby reducing the frequency of replacement and the down-time necessary for replacement. In many cases the replacement of worn parts means a loss in production and a labor loss while the equipment is idle. Therefore, a reduction in down-time increases efficiency and production.
3. Hardfacing reduces costs since wear-resistant overlays on carbon steels possessing the necessary strength, shock and fatigue resistance may be used in place of higher priced alloy steels. Worn parts which were formerly scrapped, can be hardfaced and returned to service at a cost less than that of a new part. In addition a restored part with a wear-resistant overlay will outwear a new part many times and operate more efficiently.
4. Hardfacing permits a smaller inventory of replacement parts, which reduces the spare parts investment. Another method used to reduce the number of spare parts is to reface a hardfaced part that has become worn in service. This operation may be repeated many times until the part fails due to some other reason.

ANALYSIS OF PROBLEM

To obtain maximum service life the proper type of alloy must be used for each hardfacing application. The selection of the proper type of alloy for a given application is generally a simple matter. Before choosing a hardfacing alloy it is first necessary to fully understand the service conditions under which the part is operated, then an alloy possessing the physical properties known to assure maximum life under the particular service conditions may be selected.

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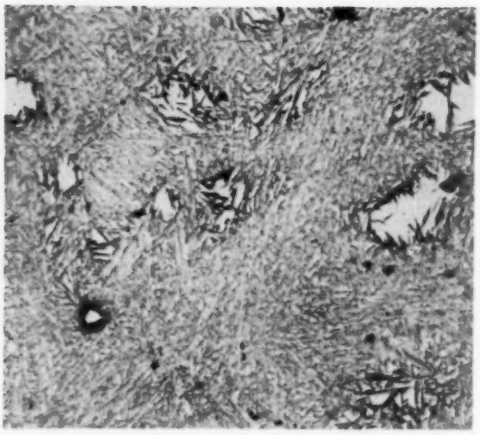

Fig. 1 Partially transformed austenite (white) and martensitic structure (gray) of 1% C – 6% Cr steel, deposited with oxyacetylene torch. Etch: Picral, HCl. × 500

Microconstituent	Microhardness, DPH
Austenite	468–518
Martensitic transformation product	482–614

The various destructive forces at work in all kinds of industrial operations may be divided conveniently into four broad general classifications. The first group includes such service conditions where impact is severe and abrasion is moderate. Typical of this group are the service conditions imposed on bucket lips. The second group includes service conditions where abrasion is severe and impact is moderate, characterized by silica particles sliding over a surface. Shock loading may also be encountered in this type of service. Typical of these service conditions is the action of the earth on plow shares. The third group comprises service conditions where various combinations of heat and corrosion with abrasion, impact and erosion are encountered such as in exhaust valves. The fourth group of service conditions involves extreme abrasion such as is encountered in earth drilling.

Fig. 2 Hexagonal and granular complex chromium carbides in alloy solid solution in iron containing 4.5% C, 30% Cr, 6% Mn and 2% Si, deposited with oxyacetylene torch. Etch: Picral. × 500

Microconstituent	Microhardness, DPH
Chromium carbides	1650–1680
Solid solution alloy	459

No one hard metal is suitable and economical for the hundreds of different applications and conditions encountered. Hardfacing alloys are of various types, each specifically designed to provide characteristics best suited to withstand the different service conditions encountered. The alloys generally employed for group 1 service may be classified as carbon and alloy steels. These are generally martensitic air-hardening steels with attainable hardness depending primarily on carbon and alloy content and cooling rate. Typical of these materials is a steel containing 6% chromium and 1% carbon. As deposited, this alloy consists of a complex martensitic type structure and partially transformed austenite as shown in Fig. 1. Various modifications in alloy content are usually made depending on service conditions and cost factors involved.

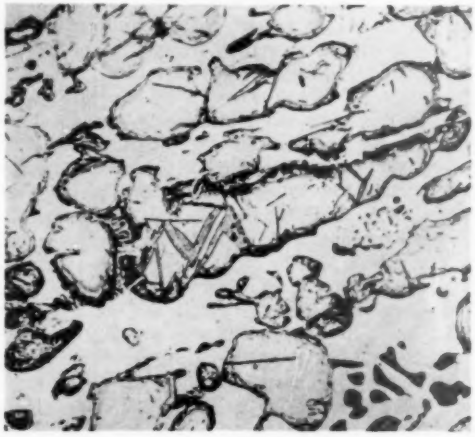

Fig. 3 Austenite islands, partially transformed austenite (with martensite needles), and carbide background in 4% C, 4% Cr, 4% Mo iron. Etch: Picral. × 500

Microconstituent	Microhardness, DPH
Austenite islands	502–614
Austenite with martensite	585–702
Carbide	1068–1230

For Group 2 service, alloy irons are generally employed. These may be of austenitic or martensitic matrix types. Typical of the austenitic iron types is the 4.5% carbon, 30% chromium, 6% manganese and 2% silicon alloy, the structure of which is shown in Fig. 2. As deposited, this material consists of alloy carbides in an austenitic matrix. The hardness of the carbides is DPH 1650–1680 and the hardness of the solid solution is DPH 459. In general, the austenitic type alloys possess better weldability than corresponding martensitic materials. In service the austenitic irons take on a high polish with use.

Typical of martensitic irons is an alloy containing 4% carbon, 4% molybdenum and 4% chromium, the struc-

ture of which is shown in Fig. 3. This material consists of a martensitic matrix containing hard carbides.

Variations in alloy content may produce either pearlitic or martensitic matricies containing hard complex carbides. Special properties may be obtained by certain alloys added in quantities sufficient to result in complex high-speed cast irons.

For Group 3 service, chromium, cobalt, tungsten alloys are generally employed. Usually these alloys are furnished in two carbon ranges, depending on the relative importance of abrasion and impact resistance. Both high and low-carbon materials exhibit high red hardness, corrosion resistance and ability to withstand the eroding action of hot gases, etc. Although the red hardness differs slightly, it is high for both types of materials.

Table 1—Hardness Values at Various Temperatures

	Room temp.	*600° F.*	*800° F.*	*1000° F.*	*1200° F.*
Low carbon	45 Rc	35 Rc	35 Rc	30 Rc	25 Rc
High carbon	56 Rc	49 Rc	47 Rc	44 Rc	37 Rc

Typical microstructures for low and high-carbon alloys are shown in Figs. 4 and 5, respectively. These alloys are complex solid solution types containing carbides. Other elements may be added to the basic alloys to confer special properties, particularly increased corrosion resistance to specific chemical attack.

Typical hardness values at elevated temperatures of both low and high-carbon materials are shown in Table 1.

In general, hardness and abrasion resistance decrease with a decrease in carbon content while toughness and impact resistance follows the opposite trend.

For Group 4 service, a deposit containing hard particles embedded in a tough matrix is used. Intermetallic compounds consisting of carbides, nitrides and borides are generally employed. Tungsten carbide is the most commonly used hard particle for service of this type. The structure of an alloy deposit containing tungsten carbide particles embedded in a low-carbon steel matrix is shown in Fig. 6. When rods of this type are applied very little of the tungsten carbide is dissolved in the steel matrix by the oxyacetylene flame or the heat of the arc. The deposit is, therefore, heterogeneous with the hard tungsten carbide particles embedded in a steel matrix. The extent to which individual tungsten carbide particles dissolve in the steel

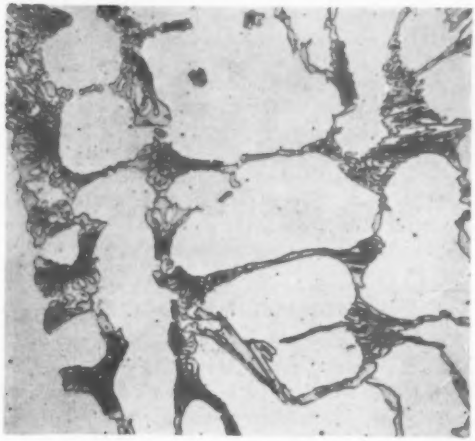

Fig. 4 Eutectic carbides and solid solution phase in 1% C, 30% Cr, 62% Co, 4% W, Fe (Bal) alloy deposited with oxyacetylene torch. Etch: Picral. × 500

Microconstituent	Microhardness, DPH
Eutectic carbide	785
Solid solution	440–455

Fig. 5 Complex carbides and solid solution matrix in 2.6% C, 3.6% Mn, 32% Cr, 43% Co, 14% W, Fe (Bal) alloy deposited with oxyacetylene torch. Etch: Picral. × 500

Microconstituent	Microhardness, DPH
Complex carbide	910–940
Solid solution	470

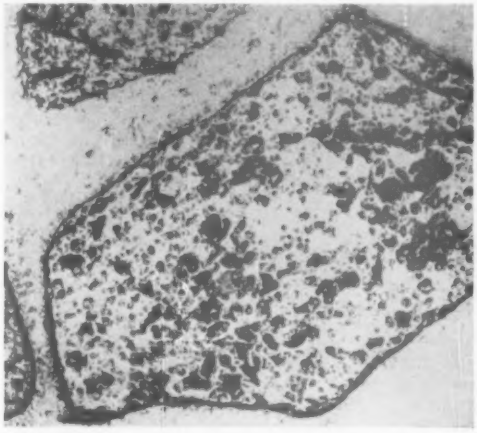

Fig. 6 Massive tungsten carbide particles in a steel matrix containing fine spheroidal carbides. Etch: Picral. × 100

Microconstituent	Microhardness, DPH
Matrix with carbide	409–455
Tungsten carbide	1873–1927

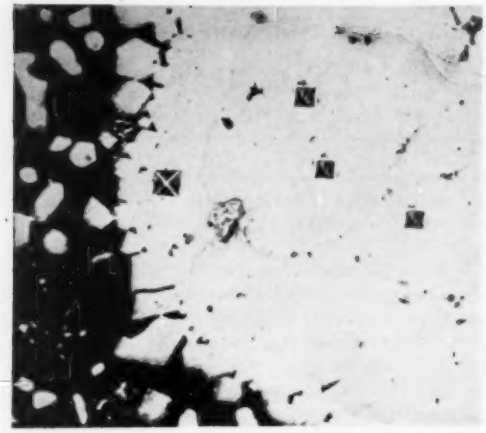

Fig. 7 Partially dissolved tungsten carbide in steel matrix. Etch: Picral. × 1000

Microconstituent	Microhardness, DPH
Center of carbide	1513–1927
Outer ring of carbide	1092–1115
Steel matrix	409–455

matrix is shown in Fig. 7. The small addition of dissolved tungsten carbide to the matrix increases the hardness of the steel a great deal in the vicinity of the carbide particles thereby providing a hard, tough binder.

The structure of a special alloy containing complex carbides and borides is shown in Fig. 8. This material is primarily used for Group 3 service even though the hardness of the individual boride particles is greater than that of tungsten carbide.

MISAPPLICATION OF HARD METALS

In a great many instances the various hardfacing alloys are misapplied. Typical of this misapplication is the practice of using a chromium, cobalt, tungsten alloy for facing agricultural implements. The abrasion resistance of this alloy for this type of service is less than that of the original material used in the implement, which results in very poor service life. In addition the cost of this alloy is appreciable.

Many of the failures in hardfacing can be attributed to the use of the wrong alloy for the job in question. Heretofore, great emphasis has been placed on proper technique of applying wear-resistant alloys whereas this has not always proved to be of primary importance from a service standpoint. Therefore, if any hard metal gives trouble in service a re-examination of the service conditions may be necessary to determine if the proper alloy has been selected for the job. Before condemning an alloy it should be determined that the proper hardfacing rod or electrode was used and the recommended technique for application was followed

No one hard metal is suitable for the hundreds of different applications encountered in industry. Proper selection of the area to be hardfaced is just as important as the alloy used. For example, on shear blades, hard metal is applied to the edge only, and not to the sides. This maintains a sharp cutting edge. Sharp blades are much more efficient than dull ones, use less power and lighter equipment is required to operate them. Interruptions in service and expense for changing blades are reduced to a minimum.

To derive maximum benefits from hardfacing the alloys should only be applied where needed. Hardfacing applied to areas not subjected to wear is wasted.

A common practice which often leads to difficulty is to select a hardfacing alloy solely on the basis of its hardness. It is an established metallurgical fact that high hardness is not necessarily a criterion for good abrasion resistance.

Selection of hardfacing alloys on a price basis also represents poor practice. In picking a welding rod or electrode for a certain application the selection must be based on the economics involved. The alloy used must give maximum service per dollar invested. For example, in a mill that is regularly down every Sunday it would be wasteful to use an alloy on wobblers that gives a life of 9–10 days. It would be better to use a cheaper alloy having a service life of 6 days.

DESIGN FOR HARDFACING

After deciding on hardfacing as a means of increasing service life, three courses are open to the user. The original worn part may be hardfaced and returned to service; a new and unused part may be hardfaced and placed in service; a part may be fabricated from a low-cost base metal with the wearing surface hardfaced.

In restoring used parts to their original condition, it is

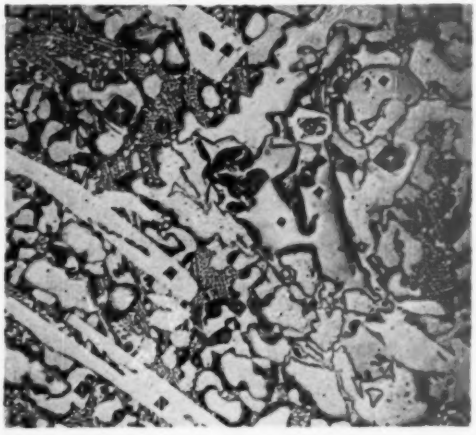

Fig. 8 Complex carbides, borides, eutectic, and solid solution phase in 1% C, 70% Ni, 15% Cr, 10% Fe (max.), 3% B alloy deposited with oxyacetylene torch. Etch: Ferric Chloride. × 500

Microconstituent	Microhardness, DPH
Boride	2470
Complex carbide	1510
Eutectic	1000–1060
Solid solution	392

Fig. 9 Building up wobblers and coupling boxes with an alloy suited for Group 1 service conditions

Fig. 10 Railroad tamping bars being restored to their original dimensions with an alloy used to meet Group 1 service conditions

well to bear in mind that hard-facing alloys are not designed to be used for complete buildup or replacement of material worn away. Generally the buildup or replacement of worn metal should be made with a welding rod or electrode of an analysis similar to that of the base metal. When the part has been rebuilt almost to size and shape, a comparatively thin layer of hardfacing material is applied to bring it to finished dimensions. Enough excess is applied to allow for finishing where this is necessary. Generally speaking, hardfacing deposits are limited to a depth not greater than $^1/_4$ in.

In protecting new and unused parts the important consideration is the selection of the proper area for hardfacing. Hardfacing applied to areas not needing protection means wasted alloys, wasted labor, wasted gas or current, and time not spent on some other maintenance job.

Where only a small surface on a part must be wear resistant, it is more economical to make the part of some low-cost material and hardface the small area subjected to wear than to use a high-priced alloy steel, case hardened or otherwise heat treated. A base metal may be selected that is better suited for the job because of strength requirements than to make a compromise between hardness and strength as would be the case if a tool steel and some form of heat treatment were selected. Only the strength, cost and availability of the base metal must be considered. After selecting a base metal a hardfacing alloy may be selected which possesses the necessary characteristics to meet the service conditions whether abrasion, impact, corrosion or heat, or any combination of these factors is involved.

Thus, a composite tool or part can be designed and constructed with the aid of hardfacing so that it will possess both strength and hardness, representing an ideal combination without any of the bad features of the homogeneous mass.

For example when hardfaced shear blades are used it is possible to use a 0.45% carbon steel rather than a tool steel, and to hardface the cutting edges with a cobalt, chromium, tungsten alloy which retains its hardness at elevated temperatures. Hardfaced shear blades cut efficiently over a long period due to their ability to maintain their hardness in the presence of high heat.

SERVICE LIFE AND COST

Savings realized through hardfacing accrue as a result of the marked increase in life and the higher operating efficiency of the protected parts. Some typical examples of the savings which may be effected through the use of hardfacing alloys follows.

Fig. 11 The flights on this cement screw conveyor have been hardfaced with an alloy suitable for Group 2 service conditions

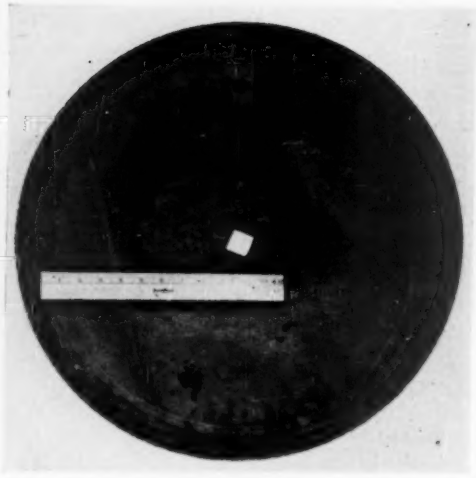

Fig. 12 Plow disks hardfaced with an alloy used to combat the effects of Group 2 service

Coke Pusher Shoes

A new shoe, which originally cost $100, pushed 41,000 tons of metallurgical coke before it was worn out and had to be replaced. The Maintenance Dept. was given the problem of restoring the shoe to its original dimensions using the high-carbon-type rod to meet Group 3 service conditions. The cost of restoring the shoe to its original dimensions was $75, which included labor, cost of the alloy and plant overhead. The hardfaced shoe after being returned to service pushed 96,000 tons of coke.

An unfaced shoe cost $0.0024 per ton of coke pushed, while a shoe reclaimed by hardfacing cost $0.00078 per ton of coke pushed. This represents a savings of $0.00162 per ton, or 70%. One coke plant pushed 6,100,000 tons of metallurgical coke in one year or a total annual savings of $9882 per shoe.

In another coke plant a gradual increase in the tonnage pushed with hardfaced shoes was noticed. This increase was attributed to the fact that the hardfacing on the bottom of the shoe tended to level off the irregularities in the brickwork which in turn decreased the wear on the shoes. This plant reported an increase in life of a hardfaced shoe over an unfaced shoe of 300%.

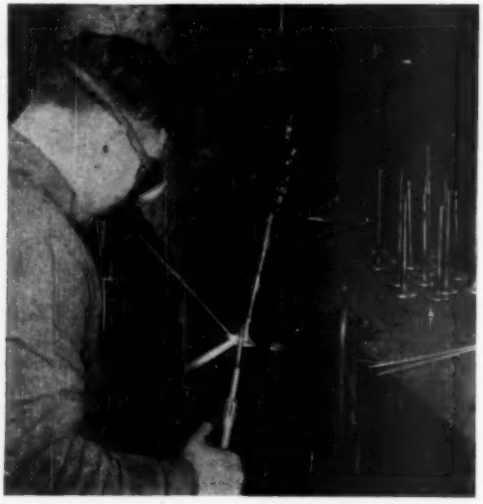

Fig. 13 Restoring exhaust valves using a low-carbon type alloy suitable for Group 3 service conditions

Clam Shell Bucket Lips

A set of new clam shell buckets cost $1100 and for an additional $50 can be hardfaced with an alloy which is suitable for Group 1 service. After being hardfaced the bucket was returned to service in a slag processing plant. It was reported that the hardfaced bucket showed a 100% increase in life over unfaced lips.

Fig. 14 A fishtail drill bit hardfaced with an alloy suitable for Group 4 service conditions

Other plants using buckets on ore bridges report an expenditure of $600 to recondition a set of badly worn buckets. However, this amount will give as much life as $2200 spent for new buckets.

It is advisable to reface the bucket lips as soon as the hardfacing shows signs of wearing away. This will keep the lips at peak efficiency, thus keeping maintenance costs to a minimum.

Diesel Engine Exhaust Valves

Diesel engine exhaust valves, which originally cost $48 each, can be hardfaced after being in service at a cost of $5.00. The hardfacing alloy used for this application is the low-carbon-type rod for Group 3 service.

The service life of an unfaced valve as reported by one railroad is 50,000 miles whereas the hardfaced valve was in service for 150,000 miles. Thus $5.00 spent for hardfacing gave as much life as $144 spent for new valves.

The number of valves in a diesel engine depends on the manufacturer of the equipment. Some manufacturers have 12 exhaust valves in their engines making

the total savings considerable. Other savings which are not apparent are savings in smaller inventories of spare valves.

Gages

One plant reports a novel application of fine particles of tungsten carbide in rod form to snap gages. A drop of the molten rod was placed on the gage after which it was ground to size. The deposit is able to resist wear better than high-speed steel and yet be less brittle than sintered carbides. These are the primary requisites for an inspection tool.

The cost of reconditioning a gage with a rod intended for Group 4 service conditions is very small when compared with the life extension. The plant reported that new gages could be used for 350 tests of size, after which the gage was discarded. The hardfaced gage gave a life extension of 30 times that of an unfaced gage. This reduces the inventory of spare parts by permitting gages to be refaced many times.

Plow Disks

One of the most profitable hardfacing operations from the users standpoint is the facing of plow disks with an alloy which is capable of resisting Group 2 service conditions. The actual cost of hardfacing a disk is relatively low. However, for the small expenditure for hardfacing over and above the cost of the disk, an increase in service life is assured. One farmer in the Midwest reported an increase in service life five times that of unfaced disks.

Plow disks are used in sets of varying number depending on the motive power available to haul the plow. The savings multiply by increasing the number of disks. There are also considerable savings in down-time and maintenance costs.

Obviously, not all of the hardfacing applications will result in such spectacular savings. In general, marked savings do result from hardfacing. In analyzing the savings, the following factors must be considered:

The additional cost due to hardfacing should be determined and compared with the savings resulting from longer life and more economical operation. Obviously, the initial cost of hardfacing is greater than that of unfaced parts. However, when the life of a hardfaced part is greater than that of a plain part the higher initial cost is absorbed many times in the over-all cost and a net savings results.

Installation, maintenance and operating costs as well as the initial cost must be included in the over-all analysis to obtain a true comparison for both hardfaced and plain parts. The over-all cost of the hardfaced and plain parts divided by the respective units of service rendered by each gives the comparative cost per unit.

SUMMARY

Hardfacing is used primarily to increase the service life of parts subjected to wear. Proper evaluation of the actual service conditions is essential for a satisfactory solution to any wear problem. Knowing the actual service conditions under which a part operates and the properties of the various hardfacing alloys, an alloy can be selected which will be best suited for the application. After selecting the alloy a study of the wear pattern will show where the material is best placed to derive maximum benefit.

In comparing the cost of a hardfaced part to an unfaced part all of the cost factors must be taken into consideration to insure proper evaluation of the economics involved.

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Welding in Steel Mill Maintenance

Maintenance operations under proper control have resulted in a better job and a saving of time and money. Organization, equipment, processes and techniques are important

by L. P. Elly

INTRODUCTION

OVER a period of years the welding and cutting arts have become familiar tools in the everyday maintenance operation. Development of welding techniques, methods, electrodes and the great increase in scope of weldability have reached a state where most maintenance jobs now require the use of the maintenance welder. The application of the welding and cutting arts to maintenance operations under proper technical supervision has generally resulted in a better job, greatly reducing the cost of repairs through the saving of many hours of maintenance labor. The expanded use of welding in maintenance has now reached a point where every departmental maintenance force includes one or more welders. Thus we see that the welder has become an indispensable, vital maintenance tool.

ORGANIZATION

Maintenance in a steel mill is a large and diverse operation, including repairs to most all types of equipment. Maintenance welding can be divided into two types; (1) the small, routine, everyday type of job and (2) the larger, more complex job. The first type of job is done without much ado by the shop maintenance welder, generally without technical supervision, the success of the job depending on the ingenuity of the welder. The second type, however, requires a technical survey by supervision in order to determine the welding repair procedure to be used, including type of electrode, extent of preheat if any, preparation of the job for welding, welding sequence, time and welding force required to meet production needs of the job and postheat if required. In addition, generally outside welder personnel, drawn from a central pool of maintenanced welders, is necessary to augment the departmental maintenance welder force in order to do this larger, more complex type of job.

The maintenance welder generally is equipped with a welding table, welding machine, preheating facilities and accessory tools in a small section of the shop. Here the smaller jobs are repair welded in order to take advantage of available equipment such as work table, vise, power-driven grinding equipment, etc. Here the welder also fabricates replacement parts, new parts and replaces metal worn away in service with weld metal. Because some welding jobs must be done in place, the welder must also be equipped with a portable welding machine, burning outfit, grinding and chipping equipment and small hand tools which he can readily transport to the job.

THE CENTRAL MAINTENANCE WELDING SHOP

In a large plant such as a steel mill the advantages of a central maintenance welding and machine shop have long been proved. To this shop is brought as much of the maintenance welding as possible in order to benefit from the economies of mechanized welding where applicable, facilities for handling all types of maintenance welding jobs, complete machining equipment and a large scope of experience in this type of work.

In smaller plants where a central shop of this nature presents too great overhead expense, its advantages can still be realized through the use of a well-equipped commercial welding shop to which work can be jobbed.

MECHANIZED WELDING

Direct operating labor today makes up over 80% of the cost of the average maintenance welding job. Rec-

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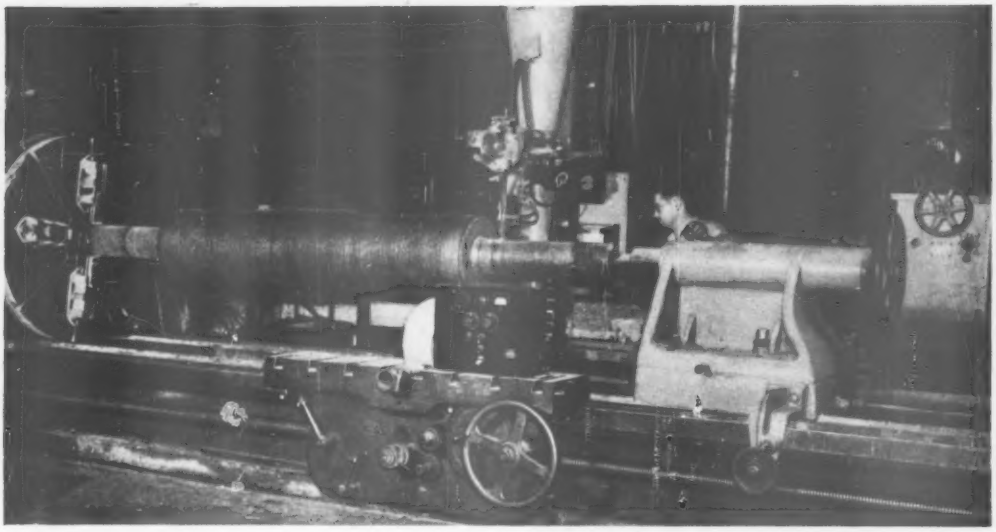


Fig. 1 Submerged arc welding lathe

ognizing this, it is obvious that the most appreciable reduction in maintenance welding costs can be obtained by the mechanization of welding wherever possible. Considerable savings can be realized through its greater deposition rate per arc hour.

Of particular note in the central maintenance welding shop is the application of the submerged arc to the build-up of worn cylindrical parts such as shafts, rods, plungers, rolls, roll necks, etc. Figure 1 shows a typical setup of equipment for building up these jobs with the automatic submerged arc welding process. It is a machine lathe which turns the work to be overlayed with weld metal and a lathe carriage which carries the welding wire feeding mechanism and the flux hopper in a lateral direction as the round is turned in the lathe. The operation is the same as a machining operation, with the welding arc, completely submerged under flux, replacing the cutting tool. The job pictured in the lathe is a worn table roller being restored to its original diameter with weld metal.

The welding wire is uncoated and fed by wire feed rollers driven by a wire feed motor. The arc voltage regulated through an electrical control circuit, varies the wire feed motor speed to automatically control the arc length. The flux is fed in two stages to the welding arc by gravity feed from the hopper mounted above. Figure 2 shows details of this two-stage method of feeding flux. Two-stage flux feeding tends to reduce flux consumption.

A vacuum recovery unit should be provided for the submerged arc equipment, with the purpose of saving labor and flux, and keeping the flux where it will do the most good—on the work, not on the floor.

In setting up this type of welding equipment, sufficient floor space should be available to (1) store work ahead of the unit, (2) provide dry storage of submerged welding flux, and (3) store welding wire in coil form. The welding wire reel on the unit should be mounted at floor level in order to eliminate excessive wire handling.

Application of welding to high-carbon and alloy steels requires preheat, and facilities should be provided for heating with fixed gas flames, not merely by a hand torch. In some cases it may be desirable to stress relieve the welded piece at some temperature above 900° F. and proximity to a suitable furnace may be a factor in locating the unit.

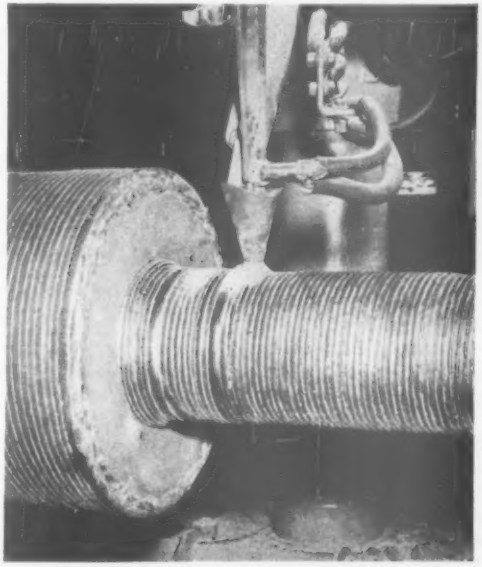


Fig. 2 Two stage flux feeding

With the submerged arc, a number of variables, including electrode type and size, flux type and size, current, voltage, surface speed and lateral feed, must be preset before starting the welding operation. Comparatively small changes in these variables radically affect results, and it is important to maintain records of both the procedure used and the results obtained. The technical supervisor should be in charge of these records and standardize procedures for the operator's use.

Although most of the automatic build-up work to date has been done with mild steel electrodes, higher carbon and alloy electrodes are available and should find increasing use as experience and data are accumulated. The following submerged arc electrodes are available: Low carbon, low alloy—high tensile, 0.60–0.75% carbon for building up wearing surfaces, S.A.E. alloys—4130, 4330, 4340 and 6150, a representative

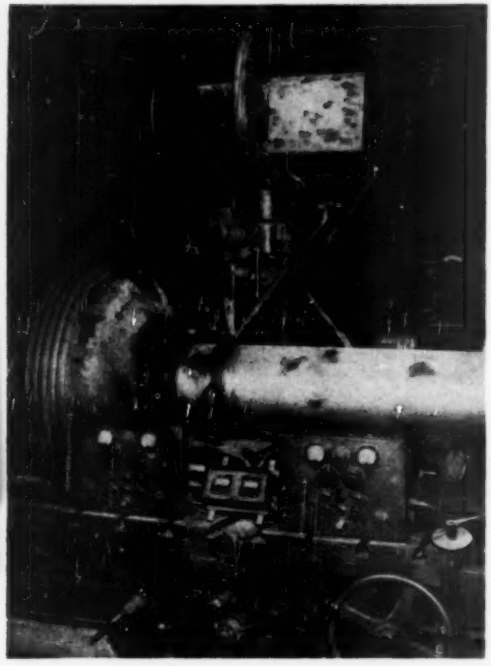


Fig. 3 Welding gas engine piston rod

range of stainless grades, 13% manganese–3½% nickel, and others. In addition, fabricated alloy wires for hard surfacing in several analyses ranging from Rockwell C32 to C55 in hardness are available.

Hard surfacing with this process should open a new field of application, because the high deposition rate possible with the submerged arc makes the application economical where the lower deposition rate of manual welding combined with high electrode costs renders many manual applications uneconomical. As the use of the process grows, the number of analyses available for deposit would be expected to increase.

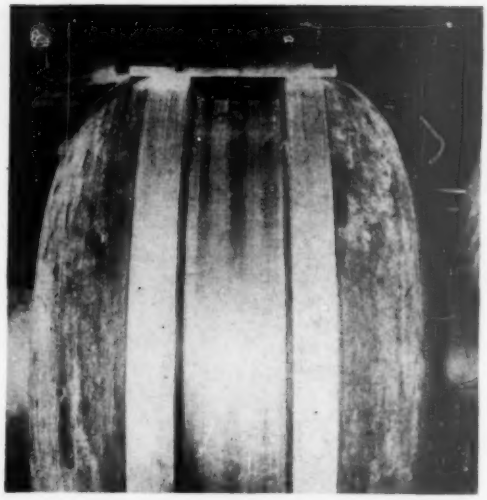


Fig. 4 Gas engine piston ready for welding

The welding current may be either a. c. or d. c. depending on availability. However, there is a decided trend to consider d. c. on build-up work because of the increase in deposition rate when the electrode is negative (straight polarity).

In addition to the submerged arc process for automatic build-up are the automatic coated wire arc process, the composite rod arc process and the flux tape process. In these the welding arc is shielded and the electrode is fed to the arc by an automatic welding head. The coated wires produce good quality weld metal, but the deposition rate is limited as is manual arc welding, by the arc characteristics.

The mechanization of maintenance welding in the

Fig. 5 Welded gas engine pistons

Fig. 6 Welding gas engine piston—submerged arc

central welding shop is further possible through the use of a manually operated submerged arc welding machine. This unit attempts to bridge the difference between fully automatic arc welding and manual welding. The machine is portable, with a cable connected to the electrode handle which is held in the operator's hand. Deposition rate and weld quality are equal to the automatic submerged arc process, while the cost per pound of deposit is slightly higher.

It is possible in the downhand position to make fillet welds, butt welds and perform build-up work with the unit, realizing deposition up to 30 lb. or better of weld metal arc per hour.

The operator is required to gage his weld size by touch and experience, but he does not feed the electrode as in manual welding, nor is his vision obstructed by the conventional welding hood. Satisfactory welds

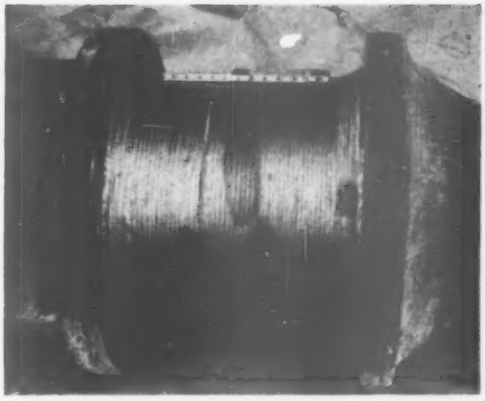


Fig. 7 Close-up of welded mill spindle journal

can be made with this unit by operators after a reasonably short training period.

SOME SUBMERGED ARC MAINTENANCE WELDING JOBS

As mentioned, the build-up of worn round parts lends itself very well to the application of the submerged arc welding process, with its high deposition rate and excellent weld metal physical properties. Several illustrations of round sections built up with this process on the equipment illustrated in Fig. 1 follow:

Figure 3 shows a 15-in. diam. gas engine piston rod being built up by the submerged arc welding unit. The welding is being done with a. c. welding current of 525 amp. arc voltage of 30 v., surface speed of 19 in. per minute and feed of $^{3}/_{8}$ in. per revolution. Weld metal deposition on this job averages approximately 16 lb. per arc hour. The machining qualities of the weld metal are excellent and the machined surface under whiting test is completely free of porosity. It is to be noticed that the fused flux readily peels itself from the

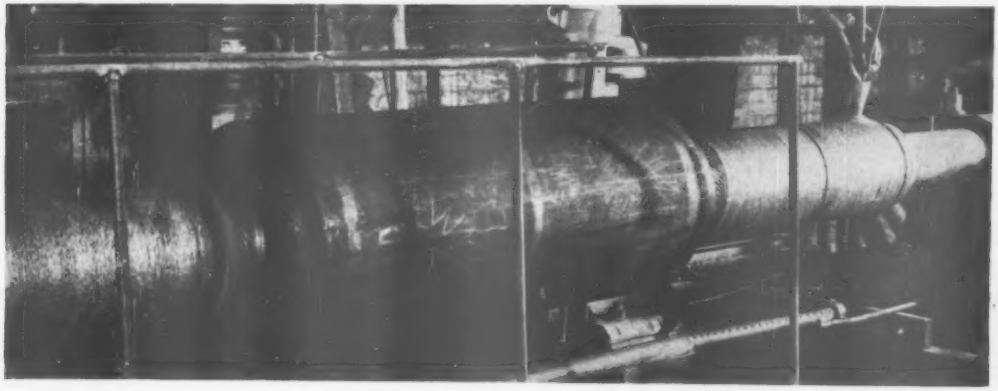
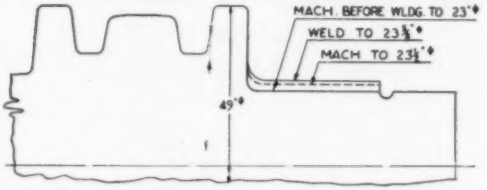


Fig. 8 Welded roll journals

weld metal as it cools and the excess unfused flux falls into a container underneath the welding job, where it is screened and restored to the flux hopper for reuse. In order that the weld metal solidifies before it tends to run, the welding arc is usually positioned about 1 to 1½ in. behind the center line of the surface being welded. This is necessary on all submerged arc welding of cylindrical shapes.

In the maintenance of gas engine pistons it is necessary to periodically rebuild the piston ring lands which wear undersize in service. Figure 4 shows the gas engine piston with the old worn lands removed, ready for sumerged arc welding. Figure 5 shows two gas engine pistons with the piston lands welded. The piston in the background was welded manually and the piston in the foreground was welded with the submerged



ANALYSIS		C	Mn	P	S	Si	Ni	Cr
	ROLL	.60	.85	.04	.04	.35	.20	.15
	WELD DEP.	.54	1.24	.03	.02	.38	.12	.05

COST		
	PREPARATION (MACH. & PREHEAT)	$ 68
	WELDING (ELECTRODE, FLUX & LABOR)	154
	FINISHING (ANNEAL, MACH & GRIND)	233
	TOTAL REPAIR COST	$ 455
	COST NEW ROLL	$4500

SERVICE		
	NEW ROLL LIFE	200,000 TONS
	ROLL LIFE BEFORE WELDING	53,000 TONS *
	ROLL LIFE AFTER WELDING	53,000 TONS

* REMOVED BECAUSE OF BADLY SCORED JOURNAL FOR WELDING RECLAMATION

Fig. 9 Data of welded roll journals

arc. The manually welded piston required 125 welding man-hours; the submerged arc welded piston, 30 welding lathe-hours. In the submerged arc welded piston the old lands were completely removed as shown in Fig. 4, and the entire section was filled with weld metal. After welding, new piston lands were then machined in the piston.

Figure 6 shows the submerged arc welding of worn piston lands by building up the vertical sides and across the face of the lands with the submerged arc. In this application the land next to the one being welded acts as a vertical dam for the flux, so that the weld metal does not run down as the weld progresses up the vertical face of the land. The two steel rings which are welded on both sides of the piston serve as a shelf to hold the flux when welding the outer edges of the piston. This method of reclamation required 20 welding

Fig. 10 Welding of 42-in. gate valve bonnet

lathe-hours. Where the worn lands are in good condition this application is the most economical of the three methods heretofore described.

Figure 7 shows the sugmerged arc welded journals

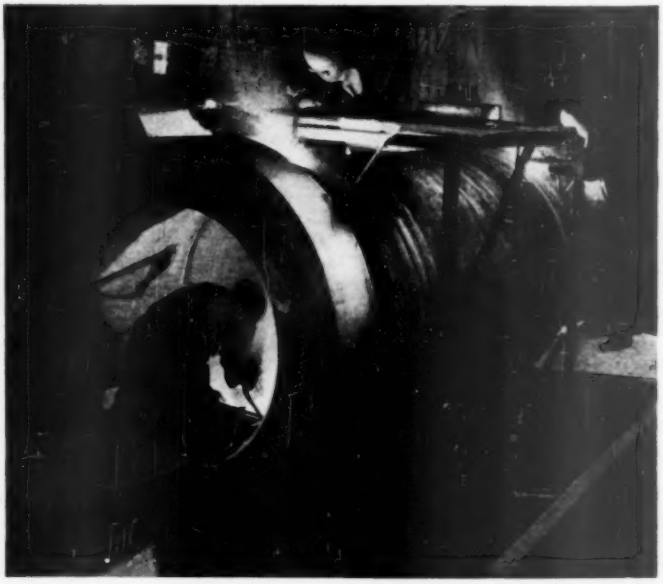


Fig. 11 Hydraulic cylinder being welded

on a mill drive spindle. The journals were worn to 18½ in. diameter and rebuilt to 20¼ in. diameter, requiring approximately 240 lb. of 0.60% carbon electrode per journal. The total arc time required for this build-up was 32 arc-hours, resulting in an average deposition of 15 lb. of weld metal per arc-hour. Both ends of the welded section were built up in order to machine to a ¾ in. radius fillet in the finished spindle.

Figure 8 shows the welded journals of a roll, the journals requiring weld metal to restore them to their original diameter. The entire roll was preheated before welding with a gas burner as pictured, the roll being encased in sheet asbestos mounted on the framework. Because of the nature of the alloy steel being welded it was necessary to pack the weld beads very closely together. In order to weld this job with five weld beads to the lateral inch it was also necessary to operate the arc at a lower voltage of 25 v. in order to obtain a small, compact weld bead. The job was welded with approximately 425 amp., 25 v., surface speed of 25-in. per minute and 3/16-in. feed per revolution.

Figure 9 shows the details of the submerged arc welding reclamation of a 46-in. cast-steel bloomer mill roll. The journals were badly scored in service which rendered the roll "scrap." The scored journals were turned down to a 23 in. diameter, welded to 23⅝ in. diameter by the submerged arc with 0.60% carbon electrode and 400° F. preheat, and then remachined to 23½ in. diameter. We see that a roll costing approximately $4500 new was reclaimed from scrap for a total cost of $455. The welded roll since welding totaled 55,000 tons of product when the journals were again scored, necessitating rewelding.

RECLAMATION OF BROKEN PARTS

The repair of damaged or broken mechanical equipment comprises a large part of the maintenance welding job. The repair job must be done in such a manner that a good balance between cost, time and quality of repair results. Generally the electric arc or the oxy-acetylene welding torch provides the necessary means to repair damaged or broken equipment. Considerable care must be exercised in this type of work, because (1) analyses vary from part to part, (2) many pieces of equipment require preheat for successful weld repair, (3) effect of preheat on adjacent parts is sometimes detrimental and (4) the location of the weld repair is very often poorly accessible and welding must be done in position.

Fig. 12 Butt welded railroad crossing

Fig. 13 Butt rail joint finish welded

Figure 10 shows the bronze-weld repair of a 42-in. cast-iron gate valve bonnet for water service. The valve bonnet was single beveled from the outside, assembled and tied together using two channels with tie rods and two heavy plates bolted across the bonnet flange face in order to maintain alignment during the brazing operation. The job was preheated with an oil torch to approximately 400 to 500° F. preheat and maintained at this temperature during the entire welding operation. Approximately 100 lb. of manganese bronze was deposited in the weld, repair requiring 12 hr. of welding time. The bonnet, after completion of welding, was slow cooled and successfully withstood a hammer testing at 110 psi. water pressure.

Figure 11 shows a large hydraulic cylinder being welded. The cylinder developed several cracks in the flange section in service. The defective flange end was machined off, a new flange section prepared and butt welded to the old cylinder wall. The double beveled "J" groove in the 8-in. wall involved 14 ft. of butt welding. The job, mounted on rollers, was preheated to approximately 300° F. by a semicircular gas burner. The circumferential butt weld is being welded from the inside at the bottom and the outside at the top. In addition, the worn bearing ring in the top end of the cylinder is being built up for remachining. Approximately 1300 lb. of E 6020 electrodes was used to complete this weld reclamation.

Figure 12 shows an over-all view of a typical steel mill roadway railroad crossing. The various converging tracks involve about 19 rail joints. Prior to pressure concrete grouting of rock ballast under and between the wooden ties, the joints were all electric arc welded. The rail ends are beveled for welding by oxyacetylene burning and the burned surfaces are ground smooth. The

Fig. 14 Welded roll neck stripped

head and web are double beveled and the flange single beveled to an included angle of 40°. The rail joint is then assembled on a $^{3}/_{4}$-in. base plate, the rail flanges skip welded to the base plate, leaving a $^{1}/_{8}$-in. gap in the weld joint. The welding is done with $^{5}/_{32}$-in. E 6012 electrodes to within $^{5}/_{32}$ in. of the top of the rail head. Two layers of hard-surfacing weld metal are then deposited on the rail head. Rails are preheated approximately 18 in. from each rail end to 500° for burning and welding. The welding is alternated from side to side after each layer when a single welder is used. However, generally two welders are used per joint. The web is welded first, the base second and the head last.

Figure 13 shows the finish welded joint ready for service. The finish welded joint has been slow cooled

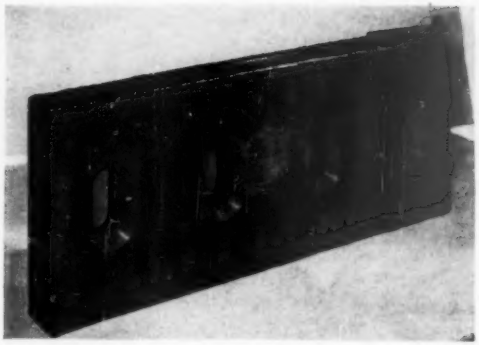


Fig. 15 Welded shear blade

and the weld reinforcement on the top and sides of the rail head has been ground off.

In the repair of heavy equipment involving large quantities of weld metal the Thermit welding process very often presents a satisfactory solution. Figure 14 shows a finishing roll neck to which a new wobbler end is welded. The neck, 20 in. in diameter, was squared and counterbored for a 3-in. pin. The new wobbler section was squared and also counterbored. The joint was then assembled as shown, leaving a 2-in. gap between the sections. After preforming the joint with wax and sand molding, the entire roll was preheated to approximately 500° by means of gas burners within a brick furnace and the area immediately adjacent to the weld preheated to approximately 1700° F. by a kerosene burner. The Thermit reaction takes place in the hopper suspended by an overhead crane above the mold and as soon as the reaction has been completed the pouring tap is opened and the molten metal poured into the

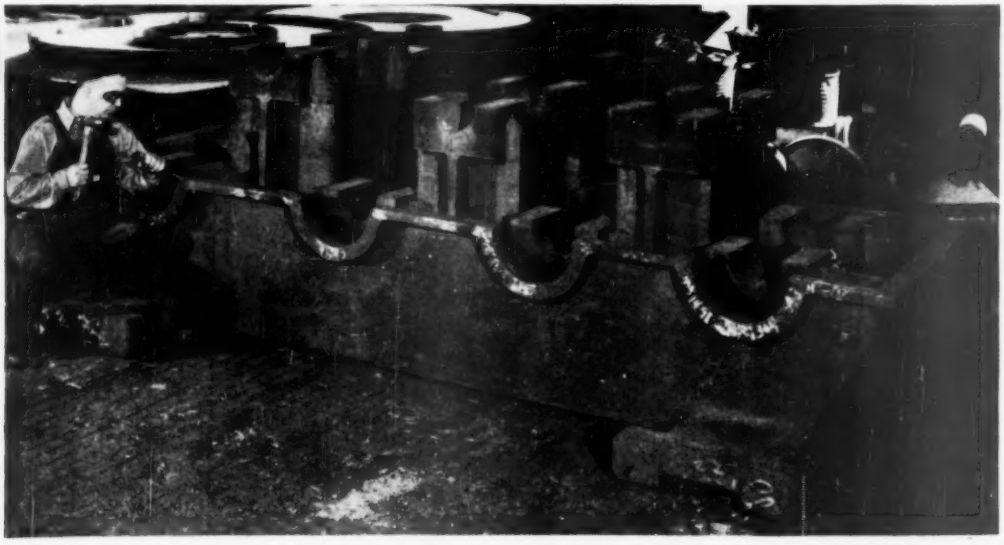


Fig. 16 Bottom section—welded gear housing

mold. Figure 14 shows the finished job stripped. The risers were then burned off with an oxyacetylene torch. The reclamation of the finishing roll, requiring 750 lb. of Thermit mixture, was done for approximately one-third the cost of a new roll.

FABRICATION OF NEW REPLACEMENT PARTS

In many maintenance welding jobs the cost of reclamation is prohibitive and it is found that the fabrication of replacement parts by welding is a more economic method of reclamation. Very often, in addition to reduction of cost, this method provides a new part which will result in better performance or longer life, or a combination of both. This type of welding is probably the most interesting done by the maintenance welder. Here the welding and cutting arts really come into their own in the maintenance welding field.

Figure 15 shows a picture of a fabricated shear blank for a hot mill shear as-welded ready for machining and grinding. The blank of 1040 analysis is surfaced with a tool steel-weld metal deposit, applied with the electric arc on all four cutting edges. This permits the blade to be turned from cutting edge to cutting edge as it wears. The short gouges running perpendicular to the knife edges are filled with hard-surfacing material to prevent the base metal from mushrooming and thus causing the tool steel weld deposit to spall. The fabricated blade has not only resulted in longer blade life than the conventional analysis shear blade, but also has shown better shearing quality. There are many possible applications in the steel mill for the weld-fabricated shear blade.

Figure 16 shows the bottom section of a straightening machine housing fabricated by welding from structural shapes and plate, cut to size by the oxyacetylene flame, and arc welded together. The split bearings are shape cut from plate and welded to the "X" shape supports. The entire assembly was stress relieved before machining.

CONCLUSIONS

The preceding illustrations give us some idea of the extent of welding being done in steel mill maintenance, clearly indicating large savings in maintenance costs. It is also to be noted that every welding process and type of welding equipment serve the maintenance operation beneficially.

The future course of maintenance welding in the steel mill will stress the centralization of maintenance welding operations in a central shop where the economies of mechanized welding and efficient supervision can be realized.

Present-day material and labor costs are high. Such an economic picture demands the successful reclamation rather than replacement of defective equipment. Recognition and use of welding in maintenance becomes absolutely necessary to meet this demand.

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(*Continued from page 11*)

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Hard Facing with Inert-Gas-Arc Welding

The inert-gas-shielded arc-welding process lends itself to hard facing and surfacings operations. Proper procedures have been developed and are described

by K. H. Koopman

INTRODUCTION

WHEN parts of machines, equipment or tools are subject to localized wear or corrosion, it is frequently advantageous to surface these areas with an appropriate alloy by means of one of several different welding processes. Surfaced parts have lasted from 2 to 44 times as long as unsurfaced parts in service. Therefore, costs of parts and maintenance and loss of production can be reduced considerably by extensive use of surfacing. Parts already worn out may be reclaimed by building up the worn areas with surfacing alloys.

In the early days of welding when the value of hard-facing and surfacing with various alloys was first recognized, the oxyacetylene welding process was used primarily. This process ordinarily produces the best quality deposits with the least amount of porosity, cracks and dilution with the base metal.

Metal arc welding soon became popular for surfacing operations because of its rapid rate of weld metal deposition, especially on relatively large masses of base metal. However, metal-arc deposits generally are less efficient than oxyacetylene deposits due to porosity and greater penetration into the base metal. The resulting greater dilution of the hard-facing alloy decreases its wear- and corrosion-resistance. Good quality deposits are made with the atomic-hydrogen process, but a slow deposition rate with high gas consumption makes this process unduly expensive.

A few Field applications and experimental tests made in the Development Division of The Linde Air Products Co. at Newark, N. J., and at the Union Carbide and Carbon Research Laboratories, Inc., at Niagara Falls, N. Y., indicated that the inert-gas-shielded arc-welding process could be applied advantageously to hard facing. The inert-gas-shielded arc-weld deposits generally were superior to metal-arc hard-facing deposits, but it was desirable to know how closely they could approach the quality of oxyacetylene deposits, made on mild steel by hand welding. It was also desired to develop procedures for surfacing mild steel with metals other than hard-facing alloys and to hard surface base metals other than mild steel.

This paper describes the results of an investigation undertaken with the following objectives:

1. Developing correct inert-gas-shielded arc-welding procedures for hard facing mild steel by hand welding.
2. Determining the quality of the hard-facing deposits.
3. Developing procedures for hard facing base metals other than mild steel.
4. Developing procedures for surfacing or cladding mild steel and stainless steel with metals other than hard-facing alloys.

Part I of the paper describes hard facing of mild steel, Part II describes hard facing of copper and copper-base alloys and stainless steel, and Part III describes surfacing of mild steel and stainless steel with metals other than hard-facing alloys.

CONCLUSIONS

1. Inert-gas-shielded arc hard-facing deposits on mild steel have substantially less dilution with the base metal than metal-arc deposits, but slightly more than oxyacetylene deposits.

2. The inert-gas-shielded arc process will produce less distortion than the oxyacetylene process because the rate of heat input is more rapid.

3. Good quality deposits, high deposition rate and low distortion obtained with the inert-gas-shielded arc process make it advantageous for use on many applications. The inert-gas-shielded arc process offers a happy medium between the oxyacetylene and metal-arc processes, with respect to distortion and deposit quality for hard facing with many alloys.

4. Backhand welding technique with ACHF (high-frequency-stabilized alternating current) is the preferred method of hard facing small sections or parts of mild steel with the inert-gas-shielded arc process. This technique produces maximum weld hardness and minimum penetration of the deposit into the base metal, and thus approaches conditions obtained with the oxyacetylene process. After the first layer is deposited, either ACHF or SPDC (straight polarity direct current) can be used for depositing additional layers of the hard-facing alloy.

4A. With forehand welding, using straight polarity direct current at high welding currents, deposition rates are $2\frac{1}{2}$ times those obtained with metal arc welding, and the deposit quality is superior to metal arc deposits. Forehand welding is recommended for hard facing massive parts or large areas because of the high deposition rates possible with good quality.

5. The inert-gas-shielded arc process produces deposits of substantially higher hardness and lower penetration than those produced by the metal-arc process.

6. An argon flow of 12 l. per minute is preferred to deposit all the hard-facing alloys at a desirable rate with the backhand technique.

7. The forehand welding technique deposits metal faster and requires a lower argon flow of 6 l. per minute, but causes slightly more dilution with the steel base metal.

8. Copper can be hard faced with No. 6 cobalt-chromium-tungsten alloy for producing excellent wear resistance.

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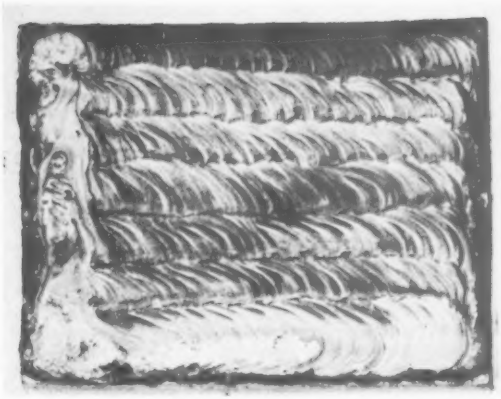

Weld No. 03001

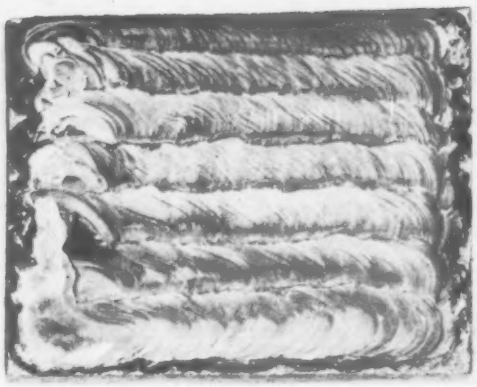

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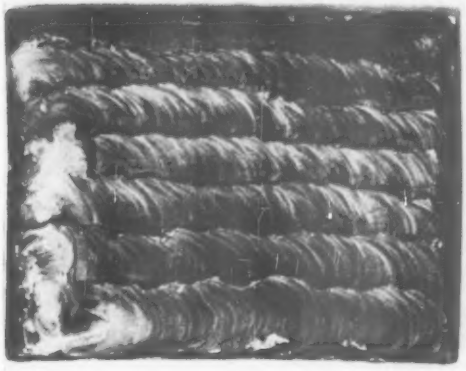
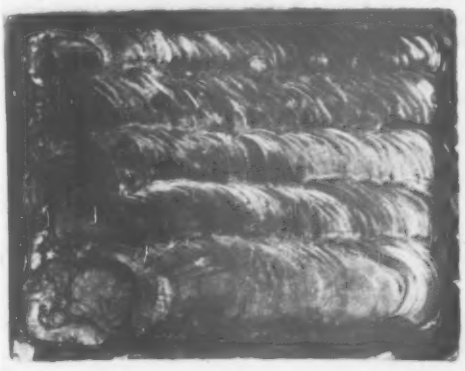
Fig. 1 Inert-gas-shielded arc deposits of No. 6 alloy on mild steel



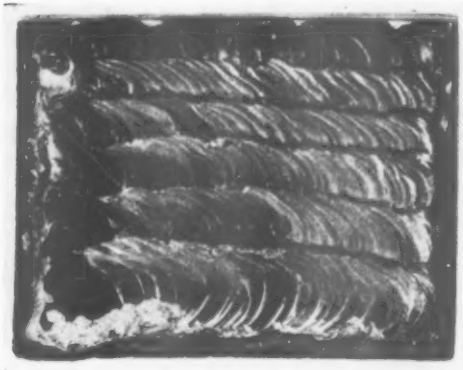
Weld No. 03013

Fig. 2 Inert-gas-shielded arc deposit of No. 12 alloy on mild steel



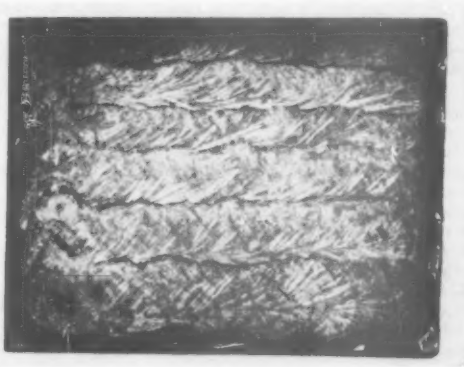
Weld No. 03009

Fig. 3 Inert-gas-shielded arc deposit of No. 1 alloy on mild steel



Weld No. 03006

Fig. 4 Inert-gas-shielded arc deposit of No. 93 alloy on mild steel



Weld No. 03030

Fig. 5 Inert-gas-shielded arc deposit of Hascrome on mild steel

9. Copper and silicon-bronze can be hard faced with aluminum-bronze.

10. Stainless steel can be hard faced.

11. Mild steel can be surfaced with aluminum-bronze, stainless steel and lead.

12. Mild steel and stainless steel can be surfaced with copper and silver.

PART I—HARD FACING OF MILD STEEL

Methods of Application

Hard-facing deposits were made on one surface of $^1/_4$- by $2^1/_2$- by 3-in. mild steel plates with a Heliarc* HW-4 torch. Various techniques of welding were tried with each type of alloy. Two different rates of argon flow, 6 and 12 l. per minute, were also tried to determine the effect of gas protection on the flowing characteristics of the hard-facing alloys.

The first layer of the deposit was made with ACHF (alternating current with high-frequency arc stabilization) and backhand technique, in an effort to make deposits having the minimum dilution of the alloy with the steel base metal.

ACHF with the forehand technique was also tried because this method was expected to allow an intermediate welding speed with moderate dilution.

DCSP (straight-polarity-direct current) with the forehand technique was tried because this method might allow the fastest welding rate, although this technique was expected to cause the most dilution due to the greater penetrating characteristic of DCSP compared to alternating current.

A second layer was deposited in order to have a deposit of about $^3/_{16}$-in. thickness for a more complete hardness survey. Either ACHF or DCSP could be used, as the weld puddle did not penetrate below the first layer and cause additional iron contamination. DCSP and the forehand technique did not produce penetration through the first layer. This method also seemed to be the fastest and required only 6 l. per minute argon flow for depositing the second layer. Therefore, DCSP with the forehand technique was used to deposit the second layer.

Test Procedure

In this investigation, several factors were considered of primary importance. Quantitative information pertaining to these factors was obtained. One factor was the time required to cover the surface of $^1/_4$- by $2^1/_2$- by 3-in. mild steel plates with one layer of the hard-facing material. Photographs of the surface of the first layer were taken. A second layer was then deposited at a higher speed (about 5 min. to deposit the second layer of all alloys) with DCSP. Photographs of the final surface of the deposit were also taken to illustrate the quality of the deposits. A few of these photographs are shown in Figs. 1 to 5.

The penetration of the alloy deposit into the base metal was also measured. This was done by measuring in thousandths of an inch the distance between the bottom of the deposit and the bottom surface of the steel plate. These measurements were taken on polished and etched cross sections. An average of 10 readings subtracted from the original thickness of each steel plate gave the penetration value. This value indicates the relative amount of dilution of the alloy with the base metal near the interface. It is a convenient method in conjunction with hardness measurements to compare the weld deposit quality with that of deposits made with the metal-arc or oxyacetylene processes.

Rockwell hardness surveys were made on the polished and etched surface of cross sections. Readings were taken on a diagonal line from the weld interface to the deposit surface. The vertical distance between each hardness reading and the weld interface was measured microscopically. This was done to determine the variation in hardness with base metal dilution. The hardness was expected to be lower near the weld bond than at the weld surface for most of the alloys tested because of the increase in iron content near the weld bond.

The general weld quality was also revealed by these cross sections.

Test Results

The details of the welding characteristics and welding time for depositing the alloys are listed in Table 1.

The surface quality and cross section of some of the deposits are illustrated by photographs.

Since the flowing characteristics and desired weld quality of each alloy are different because of differences in chemical composition, each alloy will be discussed individually. The flowing characteristics influence the amount of dilution that occurs. For example, alloys that flow sluggishly require a higher welding current to make them flow smoothly and therefore may pick up more of the base metal.

Table 1—Welding Conditions and Welding Characteristics of Alloys

Weld No.		*Argon flow,**	*Welding current amp.*	*Current*	*Technique*	*Welding time, min.:sec.*	*Remarks*
03001A	No. 6 alloy	6	100	ACHF	Backhand	22:30	Flows slowly
03002	No. 6 alloy	6	100	ACHF	Forehand	12:00	Flows well
03007	No. 6 alloy	6	120	DCSP	Forehand	11:50	Flows well
03039	No. 6 alloy	12	110	ACHF	Backhand	10:30	Flows well
03003	No. 1 alloy	6	100	ACHF	Backhand	25:00	Spatters
03004	No. 1 alloy	6	100	ACHF	Forehand	11:40	Flows well
03009	No. 1 alloy	6	120	DCSP	Forehand	11:40	Flows well
03040	No. 1 alloy	12	120	ACHF	Backhand	10:30	Flows well
03012	No. 12 alloy	6	100	ACHF	Backhand	27:00	Heavy slag
03013	No. 12 alloy	6	100	ACHF	Forehand	13:30	Some slag
03010	No. 12 alloy	6	120	DCSP	Forehand	12:40	Flows well
03041	No. 12 alloy	12	110	ACHF	Backhand	13:00	Flows well
03005	No. 93 alloy	6	100	ACHF	Backhand	24:00	A heavy scummy slag forms
03006	No. 93 alloy	6	100	ACHF	Forehand	12:30	Some slag
03011	No. 93 alloy	6	120	DCSP	Forehand	13:00	Some slag
03042	No. 93 alloy	12	120	ACHF	Backhand	11:00	Flows well
03017	Die extruded Hascrome	6	115	ACHF	Backhand	25:00	Heavy scum and spatter
03016	Die extruded Hascrome	6	100	ACHF	Forehand	12:00	Flows well
03014	Die extruded Hascrome	6	120	DCSP	Forehand	12:30	Flows well
03030	Die extruded Hascrome	12	140	ACHF	Backhand	14:00	Flows well
03033	Die extruded Hascrome	12	130	ACHF	Forehand	7:00	Flows well
03034	Die extruded Hascrome	12	130	DCSP	Forehand	12:00	Flows well
03019	Rolled Hascrome	6	115	ACHF	Backhand	...	Slag and spatter so bad that deposit could not be completed
03018	Rolled Hascrome	6	120	ACHF	Forehand	18:00	Metal spatters
03015	Rolled Hascrome	6	160	DCSP	Forehand	19:00	Heavy viscous slag
03026	Rolled Hascrome	12	140	ACHF	Backhand	11:30	Flows well
03025	Rolled Hascrome	12	130	ACHF	Forehand	13:00	Flows well
03029	Rolled Hascrome	12	170	DCSP	Forehand	7:00	Flows well

* To convert to cfh. multiply by 2.1. lmp.—liters per minute. cfh.—cubic feet per hour.

* "Heliarc" is a trademark of The Linde Air Products Co.

Discussion

*No. 6 Alloy.** This is a nonferrous alloy containing mainly cobalt, chromium and tungsten with about 1% carbon. It is one of the most widely used of the nonferrous hard-facing rods. Since dilution in metal-arc welding has been the main problem, only about 5% of the quantity of this alloy used is now deposited with this process. About 95% of the alloy used is now deposited with the oxyacetylene process.

Inert-gas-shielded arc-welding tests indicated that No. 6 alloy flowed slowly with backhand welding using ACHF and 6 l. per minute argon. When the argon flow was raised to 12 l. per minute the welding speed was approximately doubled, so that it was about the same as with the ACHF or DCSP forehand welding with 6 l. per minute argon flow.

Comparative hardness values and penetration into the base metal are given in Table A. Also included, for the purpose of comparison, are values obtained on metal-arc deposits.

Table A

Distance from weld interface, in.	*0.020*	*0.040*	*0.060*	*0.080*	*0.100*	*0.120*	*0.200*	
Welding technique	*Rockwell "C" hardness*							*Penetration, in.*
Inert-Gas-Shielded Arc[a]								
ACHF-B	38	36	38	38.5	38.5	39	..	0.022
ACHF-B[b]	40	40	42	43.5	43	..	..	0.016
ACHF-F	37	37	38	37	37.5	38	..	0.031
DCSP-F	35	36.5	38	37	37	37	..	0.026
Metal Arc[c]								
120 Amp.	28	28.5	32	39	39	39	39	...
140 Amp.[d]	27	29	29.5	30.5	34	34.5	38	...
150 Amp.[e]	28	30	32.5	35	36.3	37	39	0.050
160 Amp.	25	26.6	28	29.5	33	34.5	36.5	...
200 Amp.	24	26	27.5	30.5	33	34	..	...

[a] Two layers.
[b] This deposit made with 12 l. per minute argon flow—others with 6 l. per minute.
[c] Three layers.
[d] Could barely hold a steady welding arc.
[e] Welding current normally used.

The data indicate that the average level of hardness of the inert-gas-shielded arc deposits was higher than that of the metal-arc deposits. Also, the hardness of the metal-arc deposits was low near the weld interface. The average hardness of metal-arc deposits is Rockwell "C" 31, as given in the literature.* This compares closely with the above data at about 0.060 in. from the weld interface and is much lower than that with the forehand technique in inert-gas-shielded arc welding, but it was necessary to use an argon flow of 12 l. per minute to keep the penetration low. This gas flow rate allowed the No. 6 alloy to flow ahead smoothly. At 6 l. per minute flow rate too much heat had to be applied to make the No. 6 alloy flow ahead, causing overheating and excessive dissolving of base metal.

* Stellite No. 6 Alloy made by the Haynes Stellite Co., Kokomo, Ind.
* Haynes Stellite Co.'s literature.

The average Rockwell C hardness of oxyacetylene deposits as given in the literature* is 40, although it has been observed to average 42 on many occasions.

The hardness of the inert-gas-shielded arc deposits compares quite favorably with that of oxyacetylene deposits. The average penetration of the oxyacetylene deposits is on the order of 0.005 in. which is less than that of inert-gas-shielded arc deposits.

The inert-gas-shielded arc welding process using the ACHF backhand technique should compete favorably with oxyacetylene welding on the basis of quality for many applications. With all welding techniques, the inert-gas-shielded arc process is superior to metal-arc welding for hard facing, as indicated by these test results and by smoothness of surface.

Figure 1 illustrates the good surface of deposits made with No. 6 alloy.

No. 12 Alloy.† This is a nonferrous cobalt, chromium, tungsten alloy between No. 6 and No. 1 alloys in hardness. Since dilution is the main problem, most of this rod is also deposited by oxyacetylene welding at present.

Inert-gas-shielded arc-welding tests indicated that with 6 l. per minute argon flow a heavy slag decreased the speed of welding when backhand welding was employed. An increase in argon flow to 12 l. per minute doubled the welding speed with the backhand technique, because less slag was formed. The welding speed with ACHF backhand then compared favorably with that of forehand welding with ACHF or DCSP and 6 l. per minute argon flow.

The values of hardness and penetration are listed in Table B.

Table B

Distance from weld interface, in.	*0.020*	*0.040*	*0.060*	*0.080*	*0.100*	*0.120*	
Welding technique	*Rockwell C Hardness*						*Penetration, in.*
ACHF-B	43	44	45	45	45	44	0.015
ACHF-B*	42.7	46.5	48	45.5	45.5	47	0.014
ACHF-F	42	41	42	41	41	41	0.029
DCSP-F	36	39	42	43	43	43	0.032

* This deposit was made with 12 l. per minute argon flow—others with 6 l. per minute.

The best hardness and least penetration was produced with the backhand technique and 12 l. per minute argon flow. These hardness values are slightly less than the 48 average readings for oxyacetylene deposits. Since metal-arc welding is not normally used for depositing No. 12 Stellite, hardness values are not compared.

Figure 2 illustrates the surface of deposits made with No. 12 alloy.

*No. 1 Alloy.** This is a nonferrous cobalt, chromium, tungsten alloy containing 2.5% carbon. About two-thirds of this rod is now deposited by the oxyacetylene process and one-third by metal-arc welding.

The inert-gas-shielded arc-welding tests indicated that with 6 l. per minute argon flow the rod boiled and spattered with the backhand technique. The metal flowed well and at twice the speed with this technique when the argon flow was raised to 12 l. per minute. The welding speed then compared favorably with that of forehand welding with 6 l. per minute argon flow.

For ease of comparison, the values of hardness and penetration are listed in Table C.

It was again shown that the best hardness and least penetration was produced with backhand welding and 12 l. per minute flow. The above hardness values are equivalent to the average of Rockwell C 54 normally obtained in oxyacetylene deposits. They are superior to the Rockwell C 43 to 46 hardness of metal-arc deposits. On the basis of quality, the inert-gas-shielded arc-welding process can be considered good for application of this alloy.

As in the case of No. 6 alloy, it is of interest to note that the backhand technique with alternating current produced deposits of the highest hardness with 12 l. per minute argon flow, but lowest hardness with 6 l. per minute argon flow. With the lower argon flow the No. 1 alloy flowed so slowly that it dissolved too much of the base metal.

Figure 3 illustrates the surface of deposits made with No. 1 alloy.

† Stellite No. 12 Alloy.

* Stellite No. 1 Alloy made by the Haynes Stellite Co., Kokomo, Ind.

Table C

Distance from weld interface, in.	0.020	0.040	0.060	0.080	0.100	0.120	
Welding technique	Rockwell C Hardness						Penetration, in.
ACHF-B	50	53	54	56	51	51	0.031
ACHF-B*	54	60	58	58	58	58	0.017
ACHF-F	55	51	52	52	53	55	0.030
DCSP-F	57	57	55	56	56	55	0.022

* This deposit was made with 12 l. per minute argon flow—others with 6 l. per minute.

No. 93 Alloy. This is an iron-base alloy containing about 40% chromium, cobalt, molybdenum and vanadium. It is now deposited by the oxyacetylene and metal-arc processes. The rod is less expensive than Nos. 1, 6 and 12 alloys because of the lower alloy content.

Inert-gas-shielded arc-welding tests indicated that with 6 l. per minute of argon, a heavy, scummy slag formed when backhand welding was employed. Increasing the argon flow to 12 l. per minute doubled the welding speed with this technique because less slag was formed. This alloy flowed well with 6 l. per minute argon flow with forehand welding, either ACHF or DCSP.

The values of hardness and penetration are tabulated in Table D.

Because this rod flowed sluggishly with the backhand technique and 6 l. per minute argon flow, it seemed to dissolve more of the base metal than with the forehand welding. Therefore the hardness values listed in the first line above were low. In deposits made with the forehand technique, the hardness was quite close to the average of 62 for oxyacetylene deposits and higher than the 56 for metal-arc deposits in the as-welded condition. The hardness can be increased by 4 to 7 points Rockwell C after heat treatment consisting of heating to 1950° F. and air cooling. This heat treatment is sometimes used for this alloy.

The surface appearance of one of these deposits is shown in Fig. 4.

*Work-Hardening Alloy.** This alloy is an iron-base alloy containing chromium and manganese. It is usually austenitic and soft in the as-welded condition but in service it work-hardens considerably; that is, upon being mechanically worked, the Rockwell C hardness increases from 23 to about 43 because of a breakdown of the austenite to a martensitic microstructure.

These welding rods, both extruded and rolled, are used as bare rods for oxyacetylene welding or as coated electrodes for metal-arc welding. Most of the rods are used in the Minnesota iron mines on ore-processing equipment. Seventy per cent is deposited by the metal-arc and the balance by the oxyacetylene process at present.

Inert-gas-shielded arc-welding tests were made with $^3/_{16}$-in. diam. die-extruded rod and $^1/_8$-in. diam. rolled rod, both rods being uncoated. The die-extruded rod possessed better welding characteristics than the rolled rod, because of the slight difference in chemical composition. These rods flowed much better with 12 l. per minute argon flow than with 6 l. per minute.

The values of hardness and penetration are tabulated in Table E.

The hardness of these deposits varied considerably just as it varies from 22 to 49 in metal-arc and oxyacetylene deposits. This variation is caused by the different microstructures that exist in different zones of each successive weld bead of Hascrome Alloy. The least amount of penetration of the alloy into the base metal was produced by ACHF backhand welding with 12 l. per minute argon.

The surface of a weld deposit is shown in Fig. 5.

Dilution of the Alloy with the Base Metal. The advantage of the inert-gas-shielded arc process over the metal-arc process in reducing the contamination of the hard-facing alloy with the base metal is clearly shown in Fig. 6. The first layer of the metal-arc deposit is changed considerably in chemical composition as indicated by its etching characteristic. The deep penetration of the metal-arc deposit into the steel base metal is objectionable. All these welding tests demonstrated that on the basis of weld quality, the inert-gas-shielded arc process lies between oxyacetylene and metal-arc welding in its application to the field of hard facing. Using backhand welding technique with ACHF, the maximum weld hardness and minimum penetration of the alloy into the base metal approached closely that usually obtained in oxyacetylene welding.

Rate of Deposition of Hard-Facing Alloys. All these tests had been carried out in an effort to produce the highest quality deposits with minimum dilution with base metal. The rate of deposition was about the same as with the oxyacetylene process, namely, about 2 lb. per hour.

Additional tests were then made at high welding current values in order to determine the quality and rate of deposition with that of metal-arc deposits made at the highest rate possible.

The fastest rate of deposition of coated No. 6 alloy electrode with the metal-arc process is approximately 4 lb. per hour with a $^1/_4$-in. diam. coated electrode. The penetration of the hard-facing deposit is even more than that shown in Fig. 6, which was made at a lower welding current.

Deposits were made with the inert-gas-shielded arc process with 480 amp. straight polarity direct current and an argon flow of 10 l. per minute. The forehand welding technique was used in making these deposits of $^1/_4$-in. rod on $^1/_2$- by 3- by 12-in. mild steel plates. The rate of deposition was 10 lb. per hour which is $2^1/_2$ times the rate of metal arc deposition. As shown in Fig. 6 (*A*), the penetration into the base metal was very much less than for metal arc deposition. This inert-gas-shielded deposit had a Rockwell C hardness that ranged from 38 to 43 from

Table D

Distance from weld interface, in.	0.020	0.040	0.060	0.080	0.100	0.120	
Welding technique	Rockwell C hardness						Penetration, in.
ACHF-B	55	53	52.5	53	53.5	54	0.025
ACHF-B*	55	57	..	..	..	..	0.012
ACHF-F	60	61	60	59	60	59	0.016
DCSP-F	60	57	58	58.5	59	59	0.017

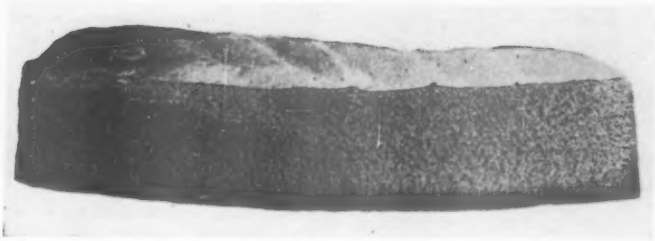
* This deposit was made with 12 l. per minute argon flow—others with 6 l. per minute.

Table E

Distance from weld interface, in.	0.020	0.040	0.060	0.080	0.100	0.120	
Welding technique	Rockwell C hardness						Penetration, in.
	Die extruded rod						
ACHF-B	21	21	20	21	20	20	0.024
ACHF-B*	28	30	29	27	28	29	0.015
ACHF-F	31	36	32	37	35	31	0.026
ACHF-F*	34	30	30	31	32	..	0.030
DCSP-F	47	43	43	32	32	..	0.025
DCSP-F*	40	42	36	30	28.5	29	0.046
	Rolled rod						
ACHF-B*	30	30	30.5	31	35	25	0.017
ACHF-F	23	27	21	..	..	..	0.032
ACHF-F*	40	40	41	35	32	32	0.036
DCSP-F	39	44	39.5	39	37	35	0.045
DCSP-F	39	36	33	31	36	34	0.036

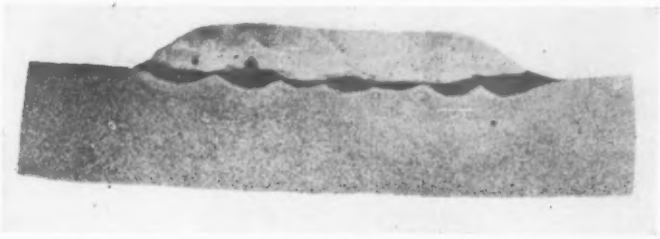
* These weld deposits made with 12 l. per minute argon flow—others with 6 l. per minute.

* Hascrome Alloy. The term "Hascrome" is a registered trademark of Haynes Stellite Co.



Weld No. 03039

Fig. 6 (Upper) Inert-gas-shielded arc weld deposit made with No. 6 alloy with ACHF. Backhand technique shows little penetration into base metal. × 2



(Lower) Metal-arc weld deposit made with No. 6 alloy at 150 amp. DCSP shows a noticeable penetration into base metal. × 2

Fig. 6 (A) Inert-gas-shielded arc deposit of No. 6 alloy made with forehand technique and 480 amp. DCSP. Rate of deposition, 10 lb. per hour. × 2

the weld interface toward the deposit surface. These values are higher than the average of 31 to be expected from metal-arc deposits made at high welding currents.

These tests indicated that the rate of deposition was 2½ times that possible with metal-arc welding and at the same time the quality of the inert-gas-shielded arc deposits was superior. A further investigation of these good test results will be conducted in conjunction with field tests in order to determine the full benefits of the inert-gas-shielded arc process to the whole field of hard facing.

PART II—HARD FACING OF COPPER, COPPER-BASE ALLOYS AND STAINLESS STEEL

*Hard Facing of Copper with No 6. Alloy**

In many cases it would be desirable to combine the good thermal conductivity of copper and the good wear resistance of a cobalt-chromium-tungsten nonferrous alloy such as No. 6 alloy. A welding procedure was developed for hard facing of copper with little penetration of the alloy into the copper. The procedure is opposite to the backhand method used to hard-face steel with a minimum of dilution.

For hard-facing of ⅜-in. thick deoxidized copper with No. 6 alloy, 180 amp. DCSP was used with a 3/32-in. diam. tungsten electrode and an argon flow of 8 l. per minute. For hard facing ½-in. thick copper, 230 amp. DCSP was used with a ⅛-in. electrode and an argon flow of 8 l. per minute. The Heliare HW-4 torch was inclined at an angle of about 60° with the horizontal and with the arc directed mainly against the welding rod after the base metal had been heated to slightly below the melting point with the arc.

* Stellite No. 6 Alloy made by Haynes Stellite Co., Kokomo, Ind.

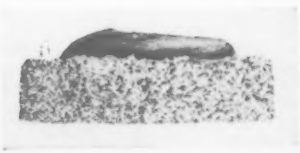


Fig. 7 Inert-gas-shielded arc deposit of No. 6 alloy on ½-in. thick copper. × 1

These deposits of No. 6 alloy on copper had a Rockwell C hardness of 42 and showed little dilution with the copper. A cross section is shown in Fig. 7. At the time these deposits were made, it was the first time that copper had been successfully hard faced with this type of an alloy.

Hard Facing of Copper and Silicon-Bronze with Aluminum Bronze†

Hardfacing of relatively soft copper and silicon-bronze with another copper-base alloy of higher hardness would often increase the life of parts made with these alloys and still give essential physical properties normally associated with these alloys. It was found that copper and silicon-bronze could be surfaced with various grades of aluminum bronze having Brinell hardness levels of 200, 250 and 300. These bronzes contain approximately 10% aluminum, 5% iron, balance copper and resist wear much better than copper and silicon-bronze. The aluminum bronzes will find increasing use in the future because of their good hardness and tensile strength.

DCSP is recommended for this surfacing with an argon flow of 6 l. per minute.

Hard Facing of Stainless Steel

Hard facing of austenitic chromium-nickel stainless steel parts is often done. Tests made indicated that the same general procedure and welding conditions should be used as for hard facing mild steel with the Co-Cr-W type alloys. In general, the hard-facing penetrates into the stainless steel slightly more than into mild steel for a given welding technique. As compared to mild steel, the lower melting temperature of the base metal allows slightly more alloying to occur.

† Made by Ampco Metals, Inc., Milwaukee, Wis.

Fig. 8 Inert-gas-shielded arc deposit of aluminum bronze made on mild steel. × 2

PART III—SURFACING OF MILD AND STAINLESS STEELS WITH ALLOYS OTHER THAN HARD-FACING ALLOYS

Surfacing with Bronze and Copper

Mild steel or cast iron parts are surfaced or built up with bronze for many applications. Welding tests indicated that these two base metals could be surfaced with aluminum bronze with the inert-gas-shielded arc-welding process. The forehand welding technique is recommended with the use of either ACHF or DCSP. For surfacing $^1/_2$-in. thick base metal, a welding current of 150 amp. was used with an argon flow of 6 l. per minute.

Three different grades of aluminum bronze were used, each having a different average Brinell hardness of 200, 250 and 300. These copper-base bronzes, containing about 10% Al and 5% Fe, flowed smoothly with no fuming during the surfacing operation, and produced a smooth sound deposit. A typical deposit is shown in Fig. 8.

Mild steel or stainless steel also can be clad or surfaced with copper, using about the same welding conditions and technique. A smooth sound deposit can be made by using a copper welding rod* containing about 0.25% Si, 0.15% Mn and 0.75% tin. Figure 9 illustrates the cross section of a deposit of copper on mild steel.

Fig. 9 Inert-gas-shielded arc deposit of copper on mild steel. × 2

Surfacing with Silver

Stainless steel was clad with silver (fine). A smooth sound deposit was made on the pickled surface of $^1/_2$-in. thick, type 347 stainless steel plates using 160 amp. ACHF and an argon flow of 6 l. per minute. No dilution of the silver could be detected as chemical composition after deposition corresponded to that of the original silver wire. The forehand or backhand welding technique can be used. DCSP was not tried, but it is reasonable to assume that it will perform satisfactorily.

* Anaconda No. 372 made by the American Brass Co., Waterbury, Conn.

Surfacing Mild Steel with Stainless Steel

Mild steel can be surfaced with most of the austenitic and ferritic type stainless steels without the use of flux. The exact welding current depends upon the size of base metal section being surfaced. Either DCSP or ACHF can be used with an argon flow of 6 l. per minute. In general, the forehand welding technique is preferred because it is the easier and more common method of welding used by most operators.

Surfacing of Steel with Lead

Mild steel has been clad with lead with this welding process also. DCSP with the forehand welding technique was found to be the most suitable. In order to promote the capillary flow of the lead along the steel surface a liquid soldering flux should be applied to the ground or pickled steel surface. Low values of welding current, 75 amp. were used to deposit the lead because it has such a low melting point. An argon flow of 4 to 5 l. per minute (about 9 cfh.) was used.

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(*Continued from page 45*)

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Effects of Arsenic on the Weldabilities of Steels

Effect of Arsenic content of base metal on the maximum hardness of affected zone of welded mild steel and alloy steels. Effects of arsenic contents of steels on their forge—weldability and oxidation. Third and fourth reports

by Harujio Sekiguchi, Seiichi Ando, Kazuo Hotta and Yoshikazu Moriwaki

IN WELDING of steel, a part of base metal adjacent to weld metal is affected and hardened by welding heat. The maximum hardness of this part of structural special steels is higher than that of low carbon steel. If the maximum hardness becomes higher, the cracking tendency in the affected zone increases.

Accordingly, cracking in the affected zone easily occurs in structural special steels in comparison with the case of mild steel. It is an interesting problem whether the maximum hardness of the effected zone becomes higher or lower when a pretty amount of arsenic is contained in the base metal.

In this report, the authors investigated the effect of arsenic content of the base metal on this maximum hardness and further on cracking in the affected zone of special steels, and from the experimental results they concluded as follows:

(*a*) The maximum hardness of the affected zone of low carbon steels increases with the increase of arsenic content.

(*b*) The maximum hardness of the affected zone of Cr-Mo steels or Si-Mn-Cr steels decreases with the increase of arsenic content.

(*c*) In case of the above mentioned structural special steels, the cracking tendency of the affected zone due to arc welding deposition decreases with the increase of arsenic content.

These facts can be explained sufficiently as follows.

If arsenic exists in ferrite grains in the state of solid solution on the one hand the hardness of the ferrite grains increases, but on the other hand the quenching hardenability of such steel decreases when the steel is cooled from higher temperature A_1 transformation point.

Harujio Sekiguchi is a Professor of the Faculty of Engineering, Nagoya University. **Seiichi Ando** is a member of the Railway Technical Research Institute, Ministry of Transportation. **Kazuo Hotta** and **Yoshikazu Moriwaki** are Graduates of the Faculty of Engineering, Nagoya University, Japan.

Abstracted from the Journal of the Japan Welding Society, Nos. 6 and 7, 1948.

It seems to be likely that the hardness of a low carbon steel is mainly influenced by the former factor, but the hardness of the above mentioned structural special steel is influenced strongly by the latter factor. If the maximum hardness of the affected zone decreases with the increase of arsenic content of the base metal, the cracking tendency of the affected zone decreases.

From various literatures, the authors are informed that as long as a large amount of arsenic is not contained in a base steel, resistance butt welding, seam welding and flash-butt welding are possible, but forge welding is impossible or difficult even if a little amount of arsenic is contained. Owing to these literatures, the authors considered that the cause of this impossibility or difficulty is the formation of oxide film by heating of the steel containing arsenic. Therefore, in order to ascertain this view, they carried out a simple forge welding and an oxidation test and they concluded as follows:

(*a*) In case of carbon steels of Cr-Mo steels, there are tendencies that with the increase of arsenic content the oxide film, which is formed by higher temperature heating, increases and the forge weldability decreases. That is to say, arsenic in steel promotes the formation of oxide film of the steel and this film interrupts forge welding.

(*b*) It seems to be likely that in case of low carbon steels containing less than 0.38% arsenic, forge welding is possible if borax is used and in case of Cr-Mo steels containing more than 0.52% arsenic, in the range of their experiment, forge welding is difficult and the upper limit of arsenic contents of forge-weldable steel was not clear for lack of lower arsenic steel specimens.

On these facts, the authors tried to make simple considerations.

With the increase of arsenic in steel, arsenic concentration increases in ferrite grains as matrix and groups of ferrite grains, which have higher arsenic concentration, are formed by segregation. Accordingly, it is supposed that the hardness of ferrite grains having higher arsenic

content is higher and their adhesive property at high temperature is lower than that of ferrite grains without arsenic.

On the ground of the experimental results and the report of Cameron and Waterhouse* (it says that if forge welding is carried out with special flux, medium carbon steels containing arsenic show good forge weldability), it is easily understood that the formation of oxide film is the important factor which interrupts the forge weldability.

* Cameron, A. E., and Waterhouse, G. B., *Iron and Steel Inst.* 113, 355–374 (1926).

The Resistance-Welding Characteristics of the Dry Disk Rectifier Welder

Discussion by T. M. Roberts

The advantages of a three-phase balanced load from the power distribution point of view are almost too well known to need mention, but this appears to be the only real advantage of this machine, despite the multiplicity of claims put forward in the article. In the introduction it is claimed that the power demand remains essentially constant regardless of machine throat depth. Examination of Fig. 9, however, indicated that this is not quite proved. Comparison of kva. demand for 18- and 60-in. throat shows that in the case of the single-phase machine the kva. demand increases by some 40%, while that of the three-phase machine increases by some 95%. This point is very good indication of the machine's sensitiveness to ohmic resistance in the secondary loop; this being so, then the system must be highly sensitive to material surface condition. The negative resistance characteristic of the rectifier would again amplify this condition when working on the low currents. This point is illustrated in Fig. 11.

It is not uncommon for machine manufacturers deliberately to design equipment with low efficiency in order to swamp the effects of external variables such as are encountered in the normal production. Since secondary resistance is important, efficient maintenance of the contact joints is essential.

No indication is given of the rectifier life and it would be interesting to know whether the internal resistance of the Mg-CuS rectifier increases with age as is the case with the copper oxide unit.

No indication is given of the effect of line voltage variations on current output, but Fig. 11 indicates that line voltage variations will have a noticeable effect when operating on low currents.

The article points out that a machine using a welding impulse of alternating polarity will produce welds which alternately offset with respect to the joint faces. The micro photographs show this point (Fig. 15), but also show that all welds are uniformally offset as produced by the dry disk rectifier machine. This is very noticeable in Fig. 25.

It is interesting to note that this machine has been used for the welding of aluminum and its alloys, but no evidence is put forward with respect to electrode pickup when spot welding these materials. The photographs indicate that pickup will be more marked on one electrode, a feature generally observed on d.c. type machines where polarity is nonreversible. The lengthy weld current cycle, combined with rather a slow initial current rise, suggests that electrode pickup would be rather troublesome.

It would be interesting to learn the reasons for the unusual lower arm design and whether this is the result of an attempt to reduce the number of joints in this member.

The foregoing comments are offered as fair criticism based on the limited amount of data provided and, no doubt, some of the points raised are susceptible to explanation. It does remain, however, for the writer to congratulate the engineers concerned for their efforts in producing a machine of novel design, capable of fulfilling some of the rather exacting requirements of the production plants. It is the writer's opinion that the machine will be most useful in the field of projection welding.

Discussion by H. E. Dixon

This is an interesting paper about an interesting process. It is very easy to read and is written in concise simple terms. One expects much from a reading of the foreword, but to the research worker the subsequent contents are rather an anticlimax. It is disappointing to find so little satisfactory evidence in support of the extensive claims made for the machine. It is not satisfactory to include macrographs without adequate description of the welding conditions or the weld properties. It is obvious, however, that fundamentally, the

T. M. Roberts is a member of the staff of the British Welding Research Assn., London, W.1., England.

The paper by R. H. Blair and C. E. Smith was published in the September 1948 issue of THE WELDING JOURNAL, p. 679.

H. E. Dixon is a member of the staff of the British Welding Research Assn., London, W.1., England.

(*Continued on page 64*)

Chrome Steel in Locomotive Firebox Applications

Results of experimental and production work performed in the welding of 18% chrome steel plates in locomotive firebox applications.

by Howard L. Miller

IN 1926 the first experimental application of 18% chrome steel side sheets was made to a Nickel Plate R. R. Mikado type freight engine. The side sheets were three-quarter side sheets and were welded in place by a representative of the Quasi Arc Co., a pioneer in production of covered electrodes. Stainless steel rods 18–8 analysis were coated by the Quasi Arc method of wrapping the rod spirally with asbestos cord, impregnating afterward with reducing agents.

These side sheets were in service 2 yr. for 130,000 miles and were removed after that period of service and found to be in excellent condition. A carbon steel side sheet from the same class of power on the same division with the same mileage was ordered out due to cracking at staybolt holes, from three to eight cracks were found in 68 staybolt holes in the hot zone of this plate. Both plates were exhibited at the Atlantic City Railroad show. The carbon steel plate had over 8 in. of curvature or dish when removed from the engine. The dish on the 18% chrome steel was not over 2 in. This showed that the chrome steel had developed much less internal strain in service than the carbon steel and would therefore be less liable to crack around the staybolt holes.

In 1930 a complete firebox, with two syphons of 18% chrome steel, was applied to a new eight-wheel switcher being built in the W. & L. E. R. R. shops at Brewster, Ohio. This firebox had been in service for 18 yr. to date. All flues and tubes have been removed four times and

Howard L. Miller, Metallurgist, Railroad Development, Republic Steel Corp., Cleveland, Ohio.

Presented at the Twenty-Ninth Annual Meeting, A.W.S., Philadelphia, Pa., week of Oct. 24, 1948.

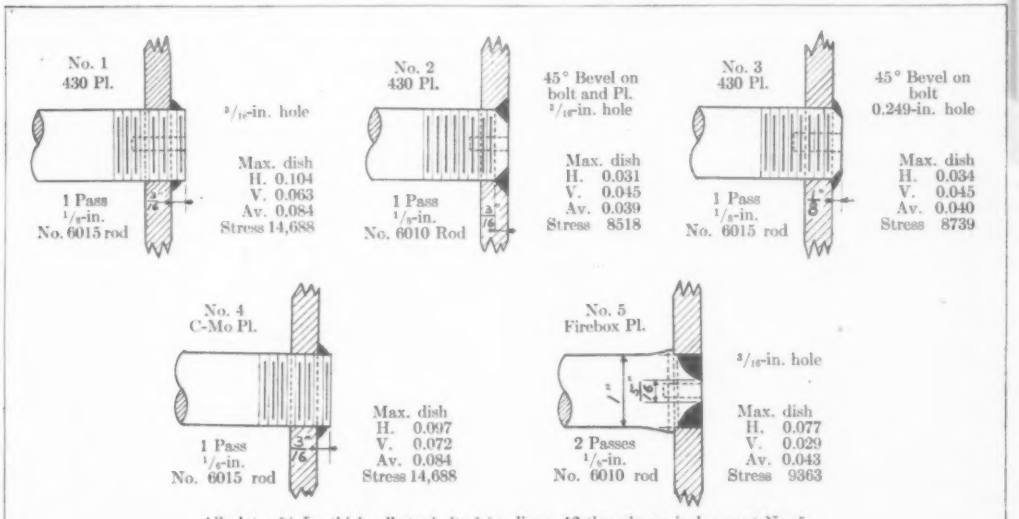
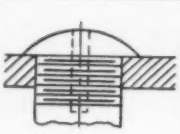
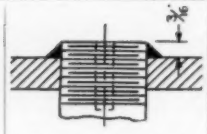


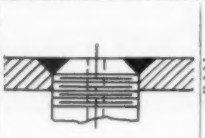
Fig. 1



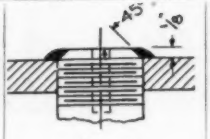
Standard riveted type
Strength of joint, average of three: C steel 21,430 lb., dish 3/8 in.; C-Mo, 25,323 lb., dish 5/16 in.; 18% Cr 25,260 lb., dish 5/16 in.



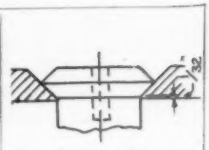
Type 1—Seal welded
18% Cr steel pl.; 1/4-in. E6013 rod. Strength of joint: 32,600, 33,535, 32,780 lb. Average of three, 32,972 lb.; dish 5/32-in.



Type 2
18% Cr steel pl. C'sk. Weld 1 bead. 1/4-in. E6013 rod. Strength of joint: 28,840, 27,110 lb. Average, 26,970 lb.; dish, 5/32 in.

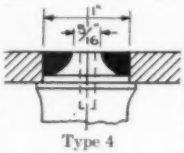


Type 3
18% Cr steel pl. 1 Pass E6013 rod shot after weld. Strength of joint: 35,000, 36,170, 36,560 lb. Average, 35,910 lb.; dish, 5/32 in.

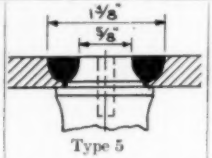


Type 8—Special beveled head
Strength of joint: Unwelded C steel pl. 120 BHN. 20, 120 lb.; 1/4-in. dish.
18% Cr 179 BHN. 32,770 lb., 1/4-in. dish.
C-Mo pl. 149 BHN. 1 Pass 1/4-in. E6010 rod. 41,340 lb., 8/32-in. dish; 38,670 lb., 8/32-in. dish. Average 40,605 lb.
18% Cr stee. 179 BHN. 1 Pass 25/20 rod 1/8 in. 42,410–42,580 lb.
C steel pl. 120 BHN. 1 Pass. 1/4-in. E6010 rod; 28,670–32,410. Flat welding 25/20 rod. 2 Passes. 18% Cr, 45,520 lb.; 8/32-in. dish. Carbon, 34,790 lb.; 8/32-in. dish

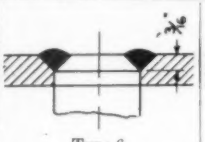
Strength of Staybolts to Pl. Joints (Pl. 3/8 in., bolts 1 in., 12 threads per inch)



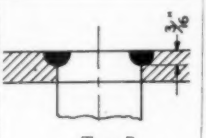
Type 4
2 Passes E6010 rod. 18% Cr steel pl. Average 21,720 lb.; dish 6/32 in. Weld too hard, try 25/20. C-Mo average, 26,160 lb.; dish 4/32 in. Both steels cupped.



Type 5
2 Passes E6010 rod. 18% Cr (swelled out). Average, 22,820 lb.; dish 1/32 in. C-Mo average, 35,535 lb.; dish 8/32 in.



Type 6
1 Pass E6010 rod. C-Mo steel. Strength of joint: 23,240 lb., dish 8/32 in.; 24,060 lb., dish 7/32 in. Average, 23,650 lb.



Type 7
1 Pass E6010 rod. C-Mo steel. Strength of joint: 29,500 lb., dish 7/32 in.; 26,570 lb., dish 7/32 in. Average 28,035 lb.

Fig. 2

are now in place for the fifth setting and welding operation with the original flue sheet still in place, and with no evidence of corrosion or cracking between the flues.

The welding was all hand welding in the production and installation of this job. All welds in syphons and firebox were butt welds only. Where 18% chrome plate was welded to the same analysis a rod containing 28% chrome with no nickel was used, the one exception being in closing up the crown sheet to syphon flange weld. In this case one edge and both ends were welded with 28% chrome rod. The other edge or side was welded with 18% chrome–8% nickel rod where the closing weld pulled against the opposite side when cooling. The greater ductility of the 18–8 rod was better in this particular case.

All welds in which common steel was welded to 18% chrome were made with a type of rod now classed as E6010. These were the firedoor flange welds and the flue-to-flue sheet welds.

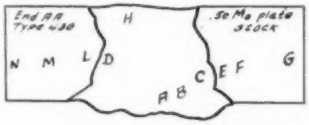
The practice followed in setting the 5-in. flues and 2-in. tubes was as follows:

The holes for flues and tubes were drilled and countersunk at a 45° slope halfway through the sheet. The tubes were swedged down as usual and the ends trimmed so that when the tube was set in the sheet up to the shoulder of the swedge, the end would not project more than 1 in. past the face of the sheet. No copper ferrules have been used at any time on this job.

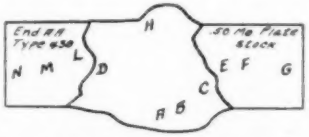
The tubes were then roller expanded lightly, just enough to fit close and then welded in without beading down. While still hot from welding, the edge of weld was run over with a beading tool to smooth down the surface and counteract the heat shrinkage effect.

In removing tubes a 45° countersunk tool with an air motor has been used to cut back the weld and tube to the original depth. The tubes are then easily loosened with a gouge and removed for cleaning. Some of the small tubes in the bottom section have been removed and replaced seven times without damage to the sheet. E6010 type rod is used in this application with normal heat and amount of metal deposited.

The steel used in these early applications contained about 0.08% carbon, 18.00% chrome and 1% silicon.



No. 2. No. 430 steel welded to 0.50 molybdenum plate stock using 25/20 1/8-in. diam. rod. 3 beads. Horizontal seam.



No. 3. No. 430 steel welded to 0.50 molybdenum plate stock using 25/20 1/8-in. diam. rod. Vertical seam

VBHN—5-Kg. Load

Position of Hardness	Sample 2	Sample 3
A	473	353
B	299	293
C	274	274
D	280	274
E	257	236
F	203	232
G	206	241
H	460	362
L	401	381
M	306	329
N	321	336

Fig. 3

This steel was somewhat brittle at room temperature.

The first two side sheets were removed because in redriving the staybolt heads after 130,000 miles we developed one small crack in each sheet at a staybolt hole. The shop temperature in October at Conneaut, Ohio, was not any too warm for staybolt driving.

The analysis has been modified to reduce the silicon to less than 0.50% and the analysis at present is actually tougher than ordinary steel at room temperature and all the way up to 1000° F.

Two other 18% chrome steel plates were installed in a nickel plate Mikado that was in service out of Frankfort for 7 yr. and were then removed because carbon steel sheets in that territory were found to be badly grooved after that amount of service. However, the 18% chrome steel was found to be in perfect condition and if it were possible to adequately inspect the inside surface along the mud ring where grooving occurs, these plates might still be in service.

In summarizing of service tests, all we can say is that so far no 18% chrome steel plate has failed in service from either corrosion or cracking or other cause not controllable. We found that with the high silicon type the plates should be heated by running live steam in the blowoff valves. When warm this steel will withstand an abnormal amount of hammering on staybolts or caulking.

If anyone should now be thinking of applying either side sheets or a full firebox of this 430 steel we can make the following recommendations as to welding practice, based on tests that have been made within the last year.

I. Procedure in applying 18% chrome steel side sheets in existing fireboxes:
   1. Remove old sheet and prepare, lay out and drill 430 steel sheet.
   2. Build up on edge of 25/20 rod bead about $^{3}/_{16}$ in. thick along top edge and ends of plate by setting plate at 45° and using a copper bar to back up the weld or use two copper bars with plate on edge in vertical position and weld in the trough.
   3. Recut the firebox to fit the edges of 430 plate and scarf the edges of old plate at 30 to 45° for welding scarf.
   4. Weld in place using 25/20 rod in usual practice as to heat except that string bead practice is better than weaving across the weld and that the sealing in weld should never run over onto the chrome plate but should stop on the built-on weld metal. This will prevent a strain from cooling, pulling directly on the plate with an as-welded structure as the built up metal acts as a cushion between the strain at the last bead fusion zone and the original fusion zone line in the 18% chrome plate.

II. New fireboxes in old or new locomotives:
   1. All welds where 18 chrome is on both sides of weld should be welded with 25/20 rod. In this case it is not necessary to build up edges before joining.
   2. All welds 18% chrome to Regular O.H. or moly or nickel steel should follow the practice in building up edges with 25/20 before welding to the other analysis.
   3. All welding should be by hand and stepback of about 6 in. runs seems to work best in joining two edges. In building up edges with 25/20 welding straightaway is satisfactory.
   4. Automatic submerged arc welding is not recommended for joining 18% chrome to other types. We have made several test runs, and the welds are sound and not hard, using a plain carbon wire with a low hydrogen flux; but the difficulty seems to be that if we weld much over 24 in. long runs the difference in shrinkage on cooling, between the low expansion stainless and the other types of steel, sets up a differential strain that causes the 18% chrome to crack along the line of fusion. With hand welding, the process is much slower and the length of heat-affected seam so much shorter that this trouble does not occur. Neither would it occur in serv-

Fig. 4 **Cold bend tests on welded Type 430 plates**

No. 1. Hand weld. LH70 electrode
No. 2. Hand weld. 25/20 electrode
No. 3. Hand weld. One side LH70 electrode. Other side 25/20 electrode.
No. 4. One side hand weld 25/20 electrode. Other side automatic weld L 60 electrode
No. 5. Automatic weld. Both sides L 60 electrode

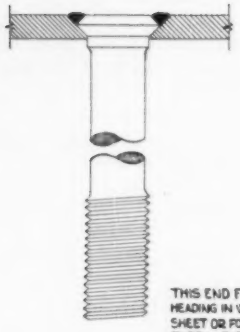


Fig. 5 Miller Staybolt

This sketch shows a section through the firebox plate of a new design head for a welded staybolt with a reduced body and one threaded end for the wrapper sheet for either a riveted end or a ball nut flexible type end

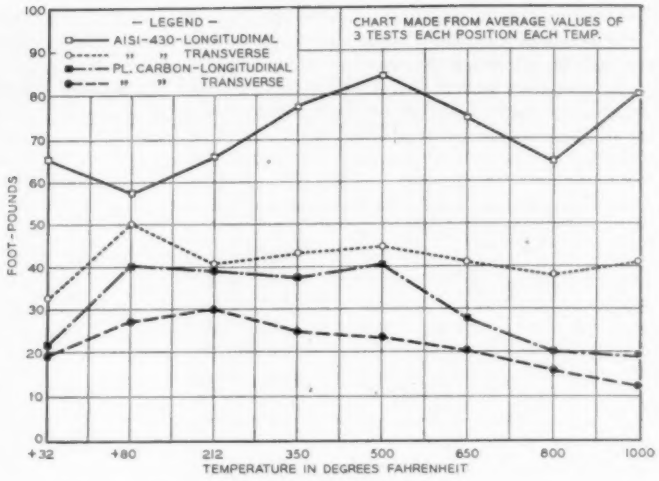


Fig. 6 Charpy impact values

Keyhole notch tests on 3/8-in. plate stock. AA Enduro (AISI 430) vs. plain carbon firebox steel at various temperatures

ice, because there the heating is general, not local, the temperature reached much lower and the rate of cooling is much slower.

Most of the interest in application of 18% chrome steel to fireboxes at present is in regard to side sheets and the lower part of the door sheet, and we have not enough tests completed to say that automatic submerged arc process will work out satisfactorily in longer seams in the same material, but it is definitely unsatisfactory in welding long seams of the 18% chrome with higher expansion steels.

5. Welding staybolts. In applying a steel for a long life expectancy some better method of setting staybolts than cold heading should be employed.

   Seal welding of staybolts after heading is now being employed by several roads but the heading operation is useless in this case as the weld would be of no value unless it melted clear through the hammered over-metal and fused into the plate itself to form a joint with the plate and the body itself of the bolt.

The writer and L. E. Grant of the C. M. St. P. & P. R. R. conducted a series of experiments on welding of staybolts in connection with the Master Boilermakers Assn. meeting in September of this year. This work undertaken to develop the extent of the stresses on the plates using different methods of welding staybolts and then to find out the actual strength of the joint between bolt and plate by pulling them apart in a special jig in a tensile testing machine.

The stress analysis tests were run by welding 25 staybolts in a 20-in. square 3/8-in. firebox plate and then measuring the depth of bulge in the plate due to weld shrinkage from welding on the one side of the plate. Results obtained were expressed in terms of the amount of "dish" or "out of flat" at the center of the plate when measured in the vertical and in the horizontal direction to obtain the average amount of "dish." This value was used as a "deflection under load" figure and the resultant stresses were calculated from this value. The chart Fig. 1 shows the resultant fiber stress on the back of the plate due to the weld shrinkage. If the plate were held flat during and after welding as in an actual firebox condition the stress on the welded side would be double the figure shown. However, the application of heat to the welded side, setting up an expansion stress on the hot side of the plate, due to the temperature difference between the hot and cold faces of the plate, will in a large measure counteract the effect of the weld shrinkage and a plate with welded staybolts might come up to service temperature conditions with little, if any, stress in the plate around the bolts. If the staybolts were cold headed the plate then would come up to heat with a considerable compression stress on the bolts and cool down with the plate around the holes in a circumferential tension stress. This is actually what causes the cracking of plate around the staybolt holes in service.

In testing the strength of joint between staybolt and plate, 4-in. diam. circles of 3/8-in. plate were cut and holes were drilled and tapped for 1-in. standard No. 12 thread, for threaded bolt tests.

Straight 1-in. diam. holes in plates were used in some tests and various other combinations of drilling and countersinking were used.

The values obtained in various designs and on plain carbon, carbon moly and 18% chrome steels were drawn up into a chart Fig. 2, which is self-explanatory.

In welding staybolts in 18% chrome plate it is con-

sidered advisable to use the E6012 for the projecting ends such as Types 1 and 3 in Fig. no. 2. The countersunk welds as in Types 2 and 8 should work better with 25/20 rod.

The beveled head Type 8 in the chart Fig. 2 and type no. 5 is being considered by several roads for application as it allows the bolt head to give a great deal of support to the plate while the weld acts both as a seal and additional wedge in resistance to pushing the plate over the bolt end. See notes at end.

In conclusion: 18% chrome steel can be and has been successfully welded to carbon steel or to itself in fireboxes and, by reason of its higher strength at elevated temperatures, its lower thermal expansion and its good corrosion resistance, should give much longer service than either ordinary steel or the regular alloys.

The Vickers Brinnell Hardness readings in the welded zone of several sample welds are shown in Figure 3 and the cold bend tests on welds in Fig. 4. Figure 6 is a chart showing the comparison of Charpy impact tests on ordinary carbon steel firebox plate and type 430 annealed steel plates. These tests were made after welding the metal at temperature one hour before testing.

ACKNOWLEDGMENTS

Acknowledgment is made by the author to the following for their valued assistance in the work involved in this report: Lincoln Electric Co., Research Dept.; C. M. St. P. & P. R. R., Test Dept.; L. E. Grant, Engr. of Tests, C. M. St. P. & P.; and Robert Grable, Met. Dept., Rep. Steel Corp.

Fabricating Aluminum Fuel Tanks with the Heliarc Process

CLEAN, corrosion-free welds were demanded in the fabrication of these aluminum fuel tanks. Each tank required approximately 40 ft. of welding. Specifications required that all inside surfaces affected by welding be cleaned of scale, weld spatter, foreign matter and also treated for corrosion. The fabricator eliminated these operations by using the Heliarc inert gas-shielded arc-welding process. Instead of flux, the Heliarc process uses argon, an inert gas, to shield the tungsten electrode and the weld area from oxidation and there can be no corrosive flux inclusion in the welds. This method of welding produces smooth, nonporous welds which are normally so clean that no postweld cleaning is required.

The tanks were fabricated from 10-gage, 3S-$^1/_2$H aluminum and all welding was done with the Heliarc HW-4 torch. The top and front side were formed from one sheet of aluminum and the bottom and back side from a second sheet. After two baffle plates were tack welded to the bottom section, the top section was put in place and tacked along the two longitudinal seams. Tack welds, 3 in. long, were made in the center and on each end of the 87-in. longitudinal seams. Between these welds, 1-in. tacks were made every 6 in. The welding operator then finished tacking the baffle plates on the inside. End plates were fitted on and tack welded every 6 in. Wear plates—$^1/_4$ in. thick, 8 in. wide and 50 in. long—were welded to the bottom of the tank. The sump was the last piece to be tacked to the tank before all the seams were completed. The two steel inlet

Fig. 1 Welding operator making the finish weld on one of the longitudinal seams

Fig. 2 Completed tank in upright position

pipes were rubber flanged and riveted to the top section prior to assembly. Total welding time, including tack welds, was approximately 1¾ hr. With the Heliarc Process the rapid welding rate results in a small heat spread, and therefore minimum warpage. This made it possible to do all assembling without the aid of any jigging.

Current used was high-frequency stabilized alternating current—100 amp. for tacking; 130 amp. for baffle plates; 150 amp. for wear plates and 80 amp. for side seams and corner welds. Filler rod (5% silicon) was added on all welds.

The inert gas-shielded arc-welding process has made rapid strides in the fabrication of all types of metal. The outstanding characteristic of the process is that, with the exception of copper, ¼ in. or thicker, flux is not required in the welding of any of the common commercial metals and alloys.

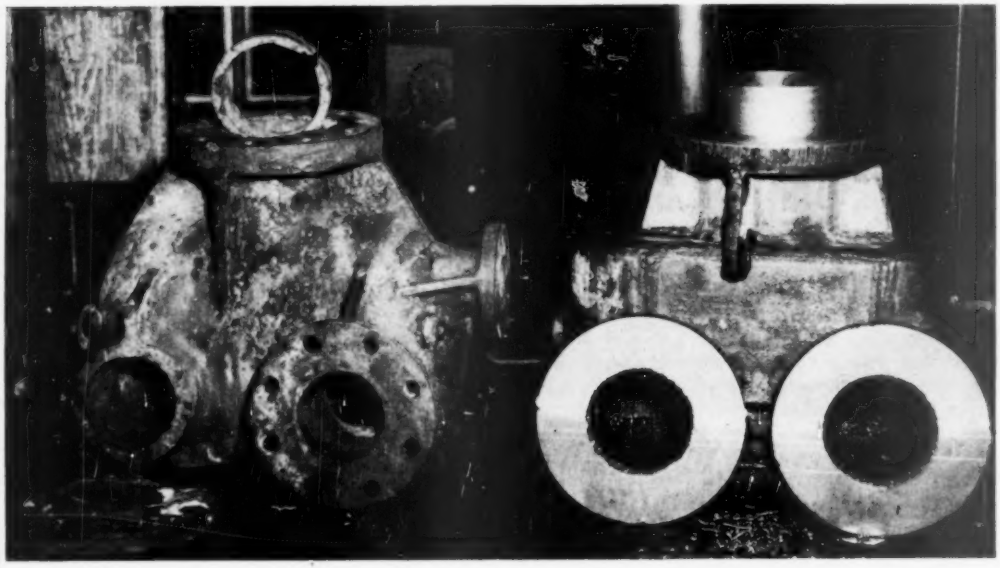


Figure 1

Valve Repair

by Paul C. Mingee

THE picture (Fig. 1) illustrates a valve fabricated by the Boiler Shop, Balboa Mechanical Division, The Panama Canal. The unusual procedure followed in the construction of this valve is a credit to welding and is not only time saving but has advantages for future repairs. The original valve, a cast-iron product (shown at the left of Fig. 1), was removed from a ship that was forced to stop for repairs while in transit of the Canal. It was found to be cracked and completely broken in places where a repair would be impracticable, as some of the fractures were inaccessible to torch or chipping gun.

After due consideration and to expedite the ship in its return to service, it was decided that fabricating the part from steel would be most practicable. It took excellent laying-out, fitting and welding to produce this complicated valve.

This all-welded job took less than half the time necessary for a casting, cut down between 85 and 100 lb. in weight and will facilitate repairs in the future and diminish the hazard of a repeated break, which is very common in cast iron.

The procedure of construction was such that the most inaccessible parts were fitted and welded first. It has three separate compartments, one each for the main and auxiliary intakes and one for the outlet. Each was tested separately by a 600-lb. hydrostatic test, as this valve works under steam pressure of 250–275 lb.

The Mechanical Division is a repair yard for transit ships and also the maintenance unit for the Canal. We have performed all types of emergency repairs without advance notice and usually work against time, using the best in equipment and mechanics to perform the work.

Paul C. Mingee is president of Boilermakers' Lodge No. 463, Balboa, C. Z.

Welded Press Speeds Production of Road Grader

By working out a careful design and fabricating a special press this company was able to save time and money in its production program of fabricating road-building machinery

by Harry P. Krull

DUE to the heavy production schedule on the Austin-Western "99-H" road grader, my company was faced with the problem of either buying another mechanical bulldozer, or building a special machine to form the bend on the front end of the grader frame which is a box section of two 12-in. channels with a top and bottom cover plate all welded together.

This special press, which was designed and built in our own plant, will weigh approximately 8 tons and cost nearly $3000, but this cost is only a fraction of the savings in increased production for which this machine is responsible.

To better understand how this arc-welded press increased production, it is necessary to give some of the details as to how the frame is formed and fabricated. To start with, the frame is fabricated from two lengths of 12-in. channel that are bent in three places; the third bend taking place after the two channels have been welded together with a top and bottom cover plate. In the first operation, the individual channels are heated to a red heat and formed against the channel web in a mechanical bulldozer to provide the height for the blade, blade attachment and hydraulic system of the grader. Then, in the same heat, they are carried to a hydraulic bulldozer where they are formed with the channel web to provide space between for the engine and transmission system of the grader. Both the left and right hand bends are made with the same die in the hydraulic bulldozer.

After the two channels cool, they are assembled in a welding fixture with a floor plate and top and bottom cover plates, and welded to form a box section at the front end of the frame. Here is where the new press takes over and this is how it has increased production: Before the new press was put into operation, it was necessary to remove the second opera-

Harry P. Krull is Welding supervisor for Austin-Western Co. Aurora, Illinois.

Data and photos courtesy The Hobart Brothers Company.

Fig. 1 A view of the hydraulic press from the operator's side with the head of the press down

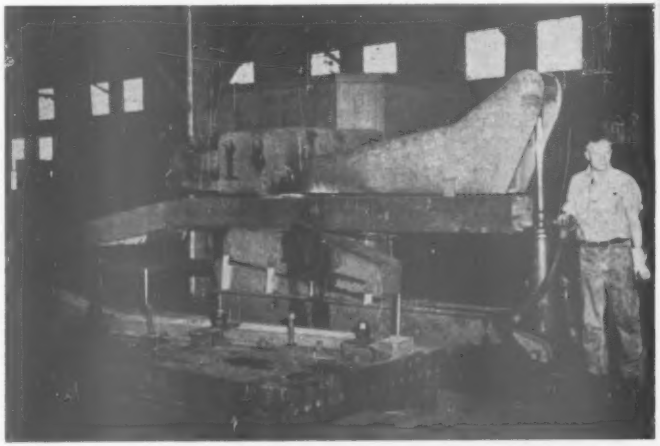


Fig. 2 The frame is now in position for forming. Note the special boxes located on the lower die to overcome a tendency of the frame to bulge before bending. The small toggle press is located above the straight part of the die and keeps the frame from kicking up during the bending

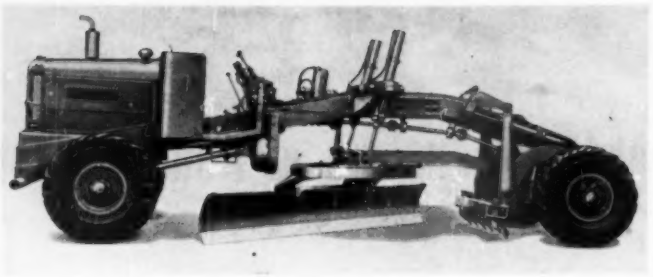


Fig. 3 The Austin-Western "99-H" road grader ready for delivery. The bend formed in the arc-welded press is located just to the right of the company signature on the frame

tion dies from the hydraulic bulldozer and insert the dies for forming the front end.

With this setup, the die change was a production bottleneck. Another thing, since the hydraulic bulldozer worked horizontally, it was necessary to place the frame on its side in an unbalanced position, which made it very cumbersome to handle. Also, the frame had to be heated to a red state over a large area of the box section and required a long time to cool off.

With the new press, the heavy dies do not have to be changed; the frame is in a balanced position as the new press works vertically; frames can be heated in a special furnace that localizes the heat to the area to be formed and the frame can be placed on a truck immediately after forming and pushed outside for cooling.

Most of the material for the press came from the scrap yard in back of the plant. The frame is made from a 15-in. I-beam and is covered with $^1/_2$-in. plate to dress it up. During the course of construction, I made notes which were useful when the machine was bored on the horizontal boring bar. It was decided to spend a little more time and money and have all holes bored accurately on the boring bar as the locking mechanism which holds the frame in the press was in reality a small hydraulic operated toggle press and the main point where the descending head pivoted was made of 5-in. heat-treated steel and extended all the way through the machine.

It will be noticed that the front end of the press has a diagonal cutoff appearance. This is due to a last minute realization on my part that I did not figure the exact amount of room needed for the hydraulic cylinder. This is another advantage of welded steel design—you can plan ahead and, if you forget anything, just make the necessary alterations with a cutting torch and continue with the arc welding.

Welding I.Q.

THE "What Is Your Welding I.Q." Quiz Box arrangement which humored, entertained and irritated hundreds in Chicago at the 1947 Exhibition of the Metal Congress was again featured at this year's Metal Congress Exhibit with a 1948 Edition. The "Quiz Boxes" were part of the Educational Exhibit sponsored by the Navy Department and furnished by the U. S. Naval Engineering Experiment Station. The forty questions of the 1948 edition of the "What Is Your Welding I.Q." are reproduced herewith, together with the correct answers.

Set I

WHAT IS YOUR WELDING I.Q.
(Welding Generators and Transformers)

	Question	Answer Yes	Answer No
1.	Variable potential sets usually have to be reset after the first 10 minutes of operation.	X	
2.	The voltmeter is the proper instrument to check the polarity of a welding generator.	X	
3.	An a.-c. voltmeter is the only instrument required to connect two welding transformers for parallel operation.	X	
4.	Welding transformers, connected in parallel, are often used as the power source for induction heating.	X	
5.	The open circuit voltage of a constant potential set cannot be varied.		X
6.	Welders' gloves worn thin and smooth are better electrical insulators than new gloves.		X
7.	Two variable potential sets, connected in parallel, are a suitable power source for brazing by resistance heating.	X	
8.	Open circuit voltage of 80 to 100 a. c. or d. c. is sufficient to kill a normal person when he constitutes the ground.	X	
9.	Under identical open circuit voltage a. c. is more dangerous to life than d. c.	X	
10.	For vertical welding it is best to set a variable potential set for the lowest applicable open circuit voltage.	X	

Set II

WHAT IS YOUR WELDING I.Q.
(Arc Welding Fundamentals)

	Question	Answer Yes	Answer No
1.	In vertical welding, depositing a heavy first pass is the proper procedure to obtain sound root condition.	X	
2.	For vertical welding in ship construction the use of $^3/_{16}$-in. diameter electrodes is mandatory regardless of the thickness of the joint.		X
3.	In vertical welding, "whipping" should be used only when unavoidable.	X	
4.	Crater blisters are usually an indication that the current rate is too high.	X	
5.	The normal current rate for E-6015 $^3/_{16}$-in. diameter electrodes is 220 amp.	X	
6.	The use of higher-than-usual current rates compensates for the presence of rust or paint on the faces of the joint.		X
7.	The normal current rate for E-6010 $^3/_{16}$-in. diameter electrodes is 180 amp.	X	
8.	The use of less than normal current rate permits welding $^1/_4$-in. stock with E-6010 $^3/_{16}$-in. diameter electrodes in any position.		X
9.	For any type electrode the arc voltage is the same regardless whether the power source is a constant potential or variable potential generator.	X	
10.	The arc voltage for $^3/_{16}$-in. diameter E-60-10 and E-6015 electrodes is the same.		X

Set III

WHAT IS YOUR WELDING I.Q.
(Low Alloy Steels)

Question	Answer Yes	Answer No
1. In welding medium carbon low-alloy steels to assure freedom from cracking of the root pass, the use of mild steel electrodes is generally permitted.	X	
2. In low-alloy steels the chemical composition of the weld metal must match that of the base metal.		X
3. In welding low-alloy steels, sounder weld metal is produced when a.-c. welding power is employed.		X
4. A.-C. welding power is preferred for fabricating complex, low-alloy steel machine elements.	X	
5. The carbon content of a low-alloy steel is not the only criterion of the preheat temperature required.	X	
6. Underbead cracking of low-alloy steels can be overcome only by preheating.		X
7. The use of electrodes with lime base covering prevents hardening of the fusion zone in low-alloy steels.		X
8. The same preheating temperature is applicable to a low-alloy steel regardless whether it is cast or rolled.		X
9. The preheat temperature for Cr-Mo steels is generally lower than for nickel steels of comparable alloy content.		X
10. The postheat treatment for manganese vanadium steels is generally lower than for nickel steels of comparable alloy content.		X

Set IV

WHAT IS YOUR WELDING I.Q.
(Welding Copper Base Alloys)

Question	Answer Yes	Answer No
1. Arc-welded naval brass weldments are not subject to stress corrosion, unless stress relieved.		X
2. Electrolytic copper cannot be successfully gas welded, but it may be brazed satisfactorily.	X	
3. Copper-nickel (70:30) alloy is usually preheated before welding.		X
4. Manganese bronze, which contains 60% copper, must be preheated regardless whether the gas- or electric-arc method of welding is employed.	X	
5. "G" bronze, which contains more than 80% copper, is normally preheated to a lower temperature than manganese bronze.	X	
6. By reason of the high preheat temperature employed, distortion is negligible in weldments of copper-base alloys.		X
7. The percentage of the copper content and the applicable preheat temperatures are directly proportional.		X
8. The welding procedure used for "G" bronze is also applicable with "M" bronze.	X	
9. In gas welding deoxidized copper sheets the first increment must be started well inside the edge.	X	
10. "M" bronze containing over 1% lead cannot be successfully welded by the oxy-acetylene process.		X

Designing for Welding—Part 1

by Wallace A. Stanley

RESISTANCE welding today offers the manufacturer numerous better, faster, simpler and lower cost ways of fabricating thousands of products. To utilize resistance welding processes to the utmost, however, parts should be designed keeping in mind the specific process and general type of equipment to be used.

Thus, resistance welding starts in the engineering department. It is the purpose of these articles to familiarize the designer with some of the basic design principles called for by the various methods of resistance welding. These illustrations and examples, it is hoped, will make easier the engineer's job in creating a design that takes full advantage of the possibilities as to appearance, life, low cost, strength, etc., obtainable by resistance welding.

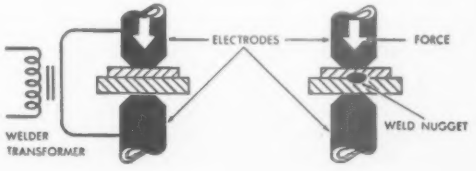
In this connection it would probably be of help at the outset to review briefly the basic types of resistance welds and their essential purposes.

Wallace A. Stanley is Application Engineer at the Progressive Welder Co.

SPOT WELDING

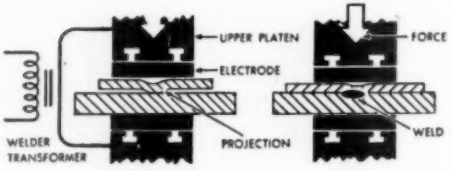
The spot weld is the simplest of all fastening devices. The simplest spot weld is made by "clamping" the parts to be joined between rod-like electrodes. Current passed through these electrodes and the metal is automatically localized where the parts touch between the electrodes. The concentrated heat melts the metal at this point and the electrodes force the pieces together forming a solid joint. After the current is shut off, the electrodes hold the pieces in place briefly while the weld cools below the plastic state.

SPOT WELDING



Spot welds may be made in many ways and combinations. They may be made singly or in pairs or in multiples. Where more than one spot weld is desired to join two pieces, the welds may be made either successively with one pair of electrodes or may be made without moving the work on multiple spot-welding machines. The number of spots depend on the nature, size and shape of the product. The method and equipment used to produce them depends on production requirements. Detail design of the part may depend on the type of equipment to be used. It is therefore advisable to take process engineering into account at the very outset of product design.

PROJECTION WELDING

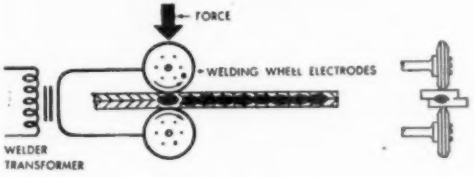


PROJECTION WELDING

Projection welds are made in much the same way as spot welds. The parts, however, are held between electrodes (dies) of much larger area. Localizing of the current is obtained by stamping or coining projections in one or both of the parts to be joined. The current passing through these projections melts the metal at the joint. Pressure between the electrodes continues until the projection has been sufficiently deformed to bring the workpieces flat against each other.

Depending on the nature of the assembly, projections may assume all kinds of shapes. A single projection will produce a spot weld. Multiple projections will produce simultaneous spot welds of equal strength. Projections also may be elongated or circular in shape, producing an elongated or annular weld, etc.

SEAM WELDING



SEAM WELDING

Fundamentally, seam welding is merely a line of overlapping spot welds produced by clamping the work between rotating wheel electrodes. Or, a single wheel may be used, with the part supported by a moving fixture forming the other electrode. Seam welding is generally performed on stationary equipment. In some instances, however, portable seam welding guns are employed. Seam welds may be either longitudinal or circular. They may be produced to be either water tight or gas tight. They may be produced singly or in pairs (on dual seam welders). Some seam welded products, for example, are cans, gas tanks, tubes, etc.

(Continued in next issue)

Discussion by H. E. Dixon

(Continued from page 54)

three-phase dry disk rectifier has several important characteristics, e.g.:

(*a*) Self Regulation. This is invaluable for automatic current correction for variations in material thickness, resistance and current shunting.

(*b*) Wave Shape. A slow rise to a constant d.-c. with negligible ripple, the duration of which is controlled by direct timing.

(*c*) Almost complete independence from effects of secondary loop inductance, and material in throat of machine, which are of such great importance in a.-c. machines.

The relatively slow rise of current to peak and control of duration by timer will be particularly useful for welding carbon steels and stainless steels and would have obvious advantages over multipulse processes for thick sheet. It does not appear to be a particularly advantageous feature in welding aluminum alloys except perhaps in thick sheets or sections requiring large energy inputs.

The disadvantages are given brief mention, namely, line voltage fluctuations have a direct effect on the energy available, and three-phase rectification is not obtained for very short welding times (less than $1^1/_6$ cycles of 60 cps. current).

The statement in the last paragraph of the paper, that if adequate power supply is available the single phase a.-c. machine is still the machine to use, is rather surprising in view of the claims made for the tri-phase welder. If this is indeed a fair comment, then it seems logical, in the absence of any direct personal experience of the equipment, that there must be some other evidence in the possession of the authors, but not revealed, which justifies the statement.

the AMERICAN WELDING SOCIETY

activities • related events

Congratulations to Vice-President R. L. Townsend

The Editor has received two very interesting documents. The first consists of a three-page newsletter which R. L. Townsend, Vice-President, District No. 6 of the AMERICAN WELDING SOCIETY, distributed to his District. Mr. Townsend is Partner of the Tweco Products Co. of Wichita, Kans. This newsletter devotes a page to high lighting the special events at the annual Meeting of the SOCIETY in Philadelphia and the Metal Congress and Exposition. The second and third pages are devoted to brief news items on individuals in the District and news of some of the happenings in the Sections of the District. This letter is accompanied by a roster of Section Officers in this District.

The second document is a regular "Twecoletter" in which the advantages of membership in the AMERICAN WELDING SOCIETY and the newly formed National Welding Supply Association are featured. Congratulations, Ray Townsend.

Naval Architects Elect Officers

At the recent annual meeting of the Society of Naval Architects and Marine Engineers, J. B. Woodward, Jr., was elected President of the Society for a two-year term beginning Jan. 1, 1949.

At this same meeting O. B. Whitaker was elected Treasurer, W. N. Landers was re-elected Secretary and Arlo Wilson was re-elected Assistant Secretary, for terms of one year starting Jan. 1, 1949.

Board of Directors Meeting

A Board of Directors meeting was held in The Bellevue-Stratford, Philadelphia, Pa., on Monday, Oct. 25, 1948, with the following in attendance:

Members: C. H. Jennings,* R. D. Thomas,* A. C. Weigel,* G. N. Sieger, O. B. J. Fraser, H. W. Pierce, G. M. Trefts III, G. E. Claussen,† J. R. Wirt, R. L. Townsend,† G. S. Schaller, R. S. Donald, C. A. Adams, D. H. Corey, L. S. McPhee, W. F. Hess, D. Arnott, T. M. Jackson, C. I. MacGuffie, J. B. Tinnon, J. J. Chyle† J. H. Humberstone,† T. B. Jefferson,† H. N. Simms and H. O. Hill.

Staff Members: J. G. Magrath, M. M. Kelly, W. Spraragen, S. A. Greenberg and F. J. Mooney.

* Retiring October 1948.
† Newly elected.

Call to Order

The meeting was called to order by President Hill at 3:45 P.M.

Roll Call

Members and staff executives were requested to rise and give their names.

A special welcome was extended to Prof. Schaller, Mr. Simms and Mr. Townsend, who came the greatest distance to attend this meeting.

The President explained that the practice instituted this year, of holding the Business Meeting of the SOCIETY and the Board of Directors' meeting at the beginning of Convention week, rather than at the close, as heretofore, is to afford all members in attendance at the Convention opportunity to attend these meetings and express their viewpoints on matters listed on the agenda. In the past, it has been necessary for many members to leave before the closing day of the Convention. The large attendance at the Board meeting indicates the desirability of holding these meetings the early part of Convention week. In future, greater advance publicity will be given the Business Meeting.

Unfinished Business 1947–48 Administration

Supporting Companies' Application Form and Certificate. The Executive Secretary displayed an application form for Supporting Companies, prepared recently at the instigation of the Sections, and with the approval of the Board of Directors.

He asked consideration of proposal to provide Supporting Companies with a certificate, similar in character to that provided a Sustaining Member, but reading as follows:

"This certifies that————Company by reason of enrollment of the required number of its personnel in the Society's membership, is a Supporting Company of the AMERICAN WELDING SOCIETY, an organization for advancing the science and art of welding and allied processes."

It was believed, generally, that such certificate, if hung in the offices of Supporting Companies, will tend to publicize the SOCIETY in places where it is not now known. The Executive Secretary was authorized to proceed with preparation and issuance of these certificates.

Having concluded the unfinished business, meeting of the 1947–48 administration was adjourned, and the 1948–49 Board convened immediately with President Sieger in the chair. The retiring members of the Board were invited to remain.

Appointments

Officers. Upon motion, duly seconded, the following officers were reappointed for the administrative year beginning October 1948: Executive Secretary, J. G. Magrath; Secretary and Asst. Treas., M. M. Kelly.

Standing Committees. President Sieger reported he was unprepared, at this time, to offer recommendations for the complete personnel of the Standing Committees, as he wished to give the matter further study. In some instances, it is his wish to confer further with the Chairman of the Committees regarding membership of the Committees and, in other instances, it has not been possible for him to obtain consent of prospective Chairmen in time for presentation of their names at this meeting. He advanced the thought there is need for change in mode of appointment. He considers it an imposition to call upon willing workers continuously to assume the burden of committee activity, and he believes provision should be made for replacements. In the case of some of our Standing Committees, as for example, the Awards and Permanent Funds Committees, the By-Laws now provide for periodic and automatic retirement of Chairmen and members of the Committees. If similar pattern is followed in the retirement of members of the other Standing Committees, the newly elected President will be saved the embarrassment of designating those personnel who are to be retired.

In offering the names of the following Chairmen of Standing Committees, he explained that selection has been made after consultation with the First and Second Vice-Presidents-elect, and replacements have been made only after conferences with and the consent of the retiring Chairmen or their representatives:

Admissions, O. T. Barnett; Constitution and By-Laws, H. M. Priest; Convention, E. V. David; Educational, R. A. Wyant; Finance, R. S. Donald; Manufacturers,*———; Membership, O. B. J. Fraser; Program, G. O. Hoglund; Public Relations, H. F. Reinhard; Publication, A. G. Oehler; Publicity, T. C. Fetherston and Section Advisory, G. M. Trefts, III.

Automatic Appointments: Awards, F. L. Plummer; Permanent Funds, R. D. Thomas and RWMA Jury of Awards, J. H. Cooper.

To expedite appointment of Standing

* Subsequent to the meeting and prior to release of these minutes, a decision based on mutual agreement between Messrs. Sieger and Tinnon has been reached to appoint E. L. Mills, Chairman, to which Mr. Mills has agreed.

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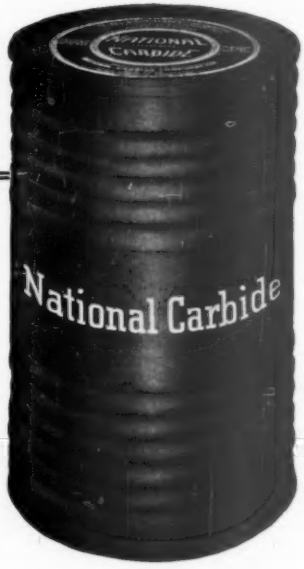

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Committees so that their work can begin with the least possible delay, Mr. Sieger stated it is his plan to request the selected Chairmen to offer recommendations for changes in present committee personnel, and as soon as these recommendations are in hand, complete lists of Standing Committee personnel will be submitted to the Board of Directors for approval by letter ballot. In the selection of personnel, the Committee Chairmen will be urged to bear in mind geographical location of members as regard need for frequent meetings of the Committee.

He plans further to request the Chairmen of Standing Committees to study the By-Laws relating to scope of activities of their Committees, with a view to submitting revisions which will permit them to engage in activities which will best further the interest and welfare of the SOCIETY. In some instances, it is believed the present scope is unduly restrictive, while in others, it overlaps the activities of other Committees. When replies are in, suggested revisions will be submitted to the Constitution and By-Laws Committee, with request that that Committee prepare suitable By-Law amendments relating to Committee appointments for consideration of the Board of Directors. The By-Laws Committee will be asked, also, to review present By-Laws relating to appointment of the Nominating Committee, and to study the By-Laws of other technical societies relating to this appointment, with a view toward offering amendments which will provide for automatic designation of individuals by nature of their elected office in the SOCIETY, in the order of prescribed national geographic representation.

A time limit is to be set for Committees to report back to the Board in order that the needed by-law changes may be made effective before the beginning of the next administrative year.

AWWA-AWS Specifications for Elevated Steel Water Tanks, Standpipes and Reservoirs

On recommendation of Mr. Hill, revision of this standard, prepared jointly by AWS-AWWA Conference Committee on Elevated Steel Water Tanks, Standpipes and Reservoirs, was approved as a joint standard of AWS-AWWA, subject to final confirmation by TAC of the AMERICAN WELDING SOCIETY, at its meeting on Oct. 27, 1948.

1949 Western Metal Congress and Exposition

In behalf of the Los Angeles Section, Prof. Schaller extended a cordial invitation to Board members to attend the 1949 Western Metal Congress and Exposition, to be held April 11 through 15, 1949, in the Shrine Pacific Auditorium, Los Angeles. The Los Angeles Section of the SOCIETY will participate in this Congress. As has been done in the past, our SOCIETY will arrange independently a program of technical meetings, and in other events, the SOCIETY will have representation on the Congress committees. The Section looks to National Officers and Headquarters for assistance in planning its program of activity. It was agreed that

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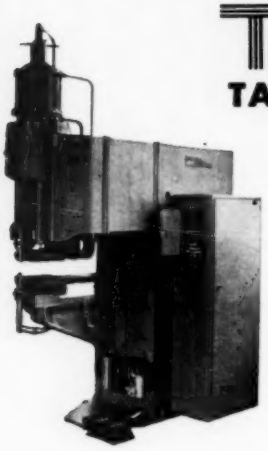

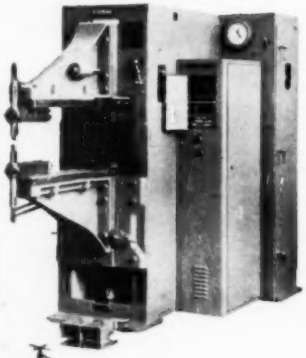

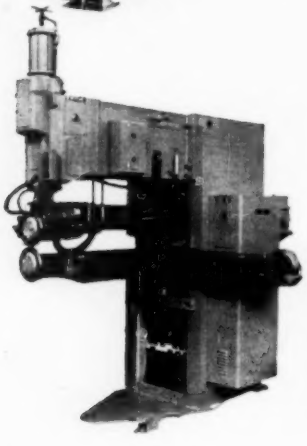

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Tri-Phase can be had in spot, projection, seam, or upset-butt welders. Ask for Tri-Phase Bulletin 10-813 just off the press.

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RESISTANCE WELDERS

when called upon, National Headquarters, Officers of the Society and National Committees concerned with meeting arrangements, will be pleased to render all possible assistance.

Membership Promotion—Institution of Program Permanent Speaker and Lecture Bureau

At request of the Executive Secretary, consideration of this matter was deferred until the next meeting.

Designation of Officers to Sign Checks and Other Documents in Behalf of the Society

As prescribed by the By-Laws, on motion, duly seconded, it was voted to authorize the Treasurer and the President, and in the absence of either, the Assistant Treasurer, to sign checks, notes, receipts, acceptances, endorsements, releases, any and all contracts and other documents, in behalf of the Society.

General Discussion on Improvement in Method of Operating Meetings of Board of Directors

All favored holding Directors' meeting the early part of Convention week, rather than the last day of the week, as heretofore. It was the consensus that this particular meeting concern itself with items of major importance to the Society, in particular, appointments, adoption of the annual budget, establishment of policies for the effective operation of the Society and to act on other matters as prescribed by the By-Laws.

In order that the budget can be prepared with some accuracy in advance of this Board meeting, it was suggested that consideration be given to advancing the dates of termination of the fiscal and membership years. It was the belief that preparation of the annual budget for the ensuing fiscal year is within the province of the retiring Finance Committee, and need not await the completion of the fiscal year. The budget can be based on experience of the past 11 months and expectency for the coming year.

Emphasis was laid on importance of including on the agenda of Board meetings only items of major importance, leaving the routine or less important matters to be acted on by the President, in consultation with other National Officers and the executive staff. Where necessary, summarized statements relating to such matters, with definite recommendations thereon, can be presented to the Board for consideration. In cases of emergency, it was believed that the Executive Committee can act in behalf of the Board, with the understanding that acts of the Executive Committee will be reported promptly to the Board for confirmation, and with the further understanding that Board members shall be afforded opportunity to attend meetings of the Executive Committee, if it is convenient for them to do so.

It was voted that at least four meetings of the Board should be held during the fiscal year—three in addition to the one held during Convention week; that two of these, in addition to the one in Convention city, be held away from Head-

How to Select the Proper Hardsurfacing Electrode

By Gorham W. Woods,
Development Engineer
The Lincoln Electric Company
Cleveland, Ohio

THE chart (Fig. 1) simplifies the selection of the correct hardsurfacing electrode for any practical requirement of resistance to abrasion and to impact. Once knowing the importance of abrasion and the necessary resistance to cracking, chipping or spalling under impact, the correct electrode can be easily chosen by its relative position on the chart. After a period of service, if it is recognized that greater resistance to wear or abrasion is necessary or that spalling or chipping is taking place, the adjacent electrode shown on the chart can be used.

From the new complete line of 14 Lincoln hardsurfacing electrodes, it is usually possible to select an electrode with exacting characteristics for any hardsurfacing need. As evident from the chart, this new complete line of electrodes has been so developed that the metallurgical characteristics overlap, thus making available a fine gradation of characteristics from which the proper electrode can be chosen.

Several new electrodes have recently been added to this hardsurfacing line. "*Tungweld*," a coated tubular electrode for AC and DC, deposits particles of tungsten carbide in a soft iron matrix, ideal for producing self-sharpening edges on earth-cutting tools. "*Faceweld*," also a coated tubular electrode for AC or DC, has been developed for hardsurfacing straight carbon, medium carbon or manganese steel to resist severe abrasion. "*Toolweld A&O*" deposits high speed tool steel for reclaiming tools and dies. "Toolweld A&O" can be air hardened or oil quenched.

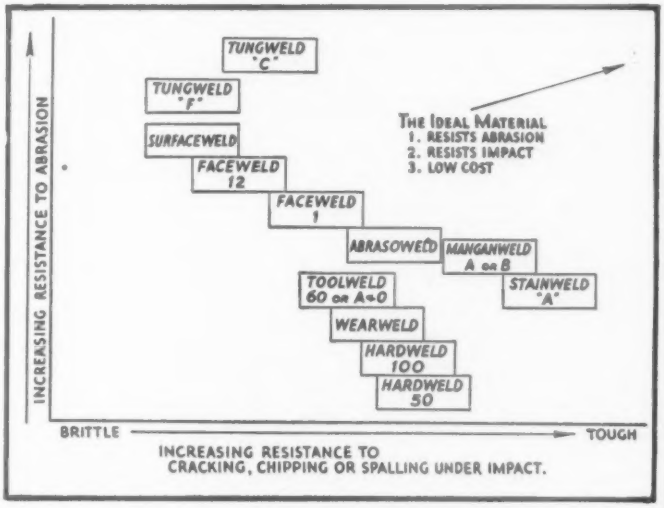

Fig. 1. Chart for selecting proper hardsurfacing electrodes to resist any combination of impact and abrasion that may be found on different jobs.

Fig. 2. A smooth, thin, self-sharpening edge of tungsten carbide particles is produced on this post hole auger by applying new "Tungweld F" electrode.

Fig. 3. Manganese steel parts subject to severe abrasion like this rock crusher bell are reclaimed with "Faceweld 1." Single layer deposits are 40 to 52 Rockwell C; multiple layer deposits are 52 to 60 Rockwell C.

Fig. 4. By laying down a high speed tool steel deposit, "Toolweld A&O" renews this stamping die at an unusually low cost for an additional 40,000 parts.

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quarters city, but because of improbability of obtaining a quorum, the two out-of-town meetings be held no further west or southwest than Chicago or St. Louis. It was believed advisable to hold one of the out-of-town meetings in the city where the ensuing Convention is to take place. It was suggested that invitation to Board meetings be extended to Section Officers in city where Board is meeting. It was recommended that Board meeting notices be sent out two weeks or more in advance of the meeting.

The discussion resolved into the following motions:

1. That the next meeting of the Board of Directors be held in New York on Dec. 2, 1948, for the primary purpose of considering and acting on the 1948–49 annual budget, and in acting on other matters requiring early attention;

2. That at least four meetings of the Board of Directors be held during a fiscal year, including that held during the Annual Convention—time and place of these meetings to be determined by the President, bearing in mind it is the wish of the Board that two, in addition to the one held in Convention city, be scheduled away from Headquarters' city;

3. That steps be taken to ascertain legality of retiring Finance Committee recommending a budget for the ensuing fiscal year to the new administration, and further, that investigation be made to determine feasibility of having the fiscal and membership years terminate at the same time;

4. That invitation to Board meetings be extended to Section Officers in cities where Board meetings are held;

5. That the business of the Board meetings be arranged to conserve time of Board members, in so far as possible;

6. That the Executive Committee of the SOCIETY act in behalf of the Board of Directors only in cases of emergency, with the understanding that acts of the Committee will be reported promptly to the Board, and the Board will be given opportunity to revoke such actions, if deemed necessary, and with the further understanding that Board members shall be afforded opportunity to attend Executive Committee meetings, when they can conveniently do so.

A.S.T.E. Meeting

The Seventeenth Annual Meeting of the American Society of Tool Engineers will be held Mar. 10th, 11th and 12th, in Pittsburgh, according to an announcement by Irwin F. Holland, President of the Society.

Tool engineers from throughout this country and Canada will gather in the Hotel William Penn for a series of technical sessions on new developments and problems in the tool engineering and related fields.

Scheduled for Thursday and Friday evenings and Saturday morning, the technical sessions will open with a discussion on "Forging Dies Design," "Industrial Applications of Glass" and "Color Dynamics." The March 11th evening session will consist of discussions on "Machining and Forming of Corrosion-Resistant Steel." Saturday morning tool engineers will hear speakers on "Metallic Spraying of Hard Metals" and "Problems in Machining Aluminum."

Tours of plants in the Pittsburgh area, always a major feature of A.S.T.E. National Meetings, will offer tool engineers a unique opportunity to view operations in a wide variety of industries.

Employment Service Bulletin

Service Available

A-565. Position wanted. Graduate Engineer with twenty-two years experience in industry, twelve years of which have been as Welding Supervisor and Engineer in charge of oxyacetylene welding and cutting, electric arc welding, resistance welding, flame hardening, case hardening, heat treating and metallizing. Can handle design and supervise production. Desire position with concern doing volume of production or maintenance welding, heat treating, etc.

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Saze System Welded Connection Units for welded assembly

Saze Units place in position and securely hold together structural parts to be welded.
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They produce a fine-grained weld of high tensile strength—a steady flowing flame which does not wander and which is concentrated at the desired focal point. Heavy copper coating permits gripping at the extreme ends—eliminates frequent re-setting. For excellent results — *every time* — specify BBB Keen-Arcs by name.

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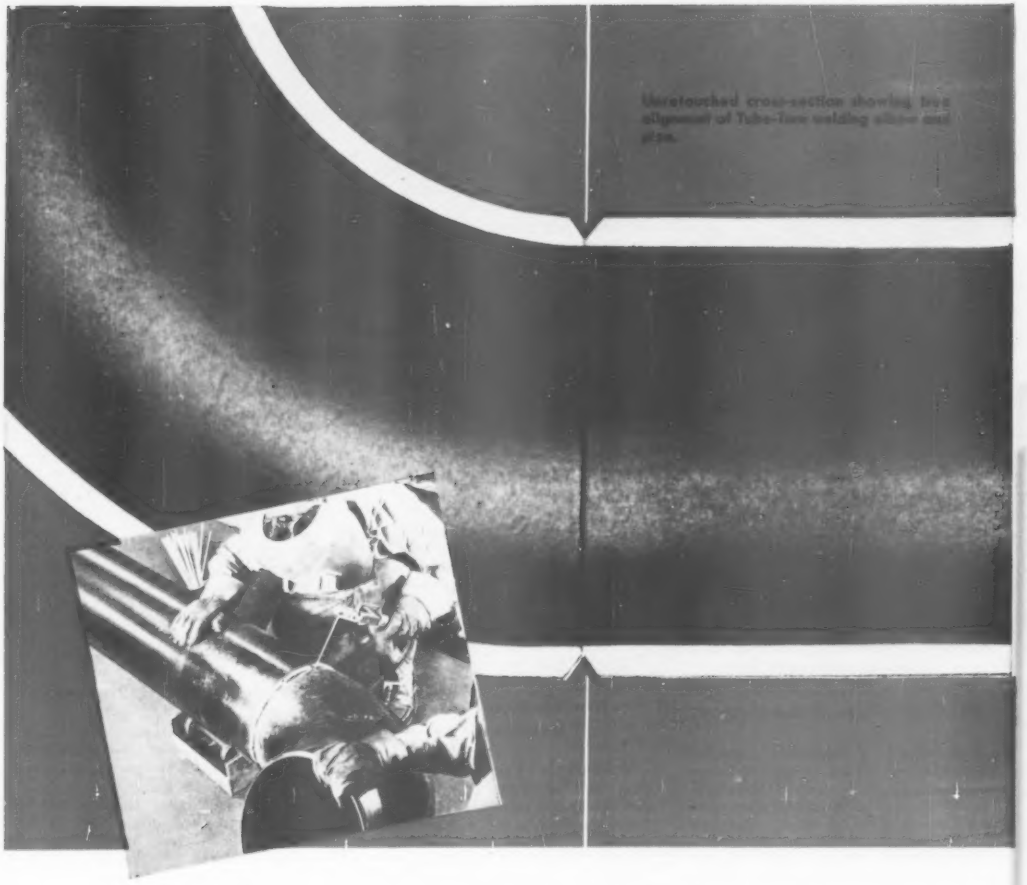

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Tube-Turn welding fittings are manufactured by the firm with the nation's biggest backlog of experience in welding fittings. They fill the bill, all ways.

If you want strength, you've got it through Tube Turns forging know-how. If you want minimum flow friction and pressure loss, you get it with the smooth inner walls and the smoothly functional design of Tube-Turn welding fittings. And if you want certain types and sizes in a special metal or alloy, your chances of getting it are good when you deal with the Tube Turns distributor. He handles the biggest line of welding fittings.

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Write for folder, "Dimensional Data and Weights of Tube-Turn Welding Fittings." Opens to series of quick-reference tables.

NEWS OF THE INDUSTRY

Engineers of Energy

Under the above title the M. W. Kellogg Co. received an interesting write up in the November 1948 issue of *Fortune*. We quote two subtitles from this article.

"This almost unknown company develops, designs and builds over half the world's oil-cracking capacity, in every geographic area for all the oil majors."

"M. W. Kellogg, a mighty engineer of oil refineries, moves toward volume chemicals and atomic power for industry."

They Were Carrying the Wrong Torch

Safe burglars went to work with an acetylene torch in the office of a Baltimore theater. The torch blazed and blazed but the safe wouldn't come open. They gave up in disgust and left their equipment behind, police reported. Instead of a cutting torch they had used a welding torch—and left the safe door closed tighter than they had found it.

Welded Bridges of the Future

Foreseeing a tremendously expanded application of welded design to bridge construction, the Trustees of The James F. Lincoln Arc Welding Foundation are sponsoring a new Award Program to advance the progress of welded bridge design.

The "Welded Bridges of the Future" Award Program offers awards to bridge or structural engineers for the best designs of a specified, welded highway bridge. The first award is $3000; the second award $1500; third award $750. In addition to the awards for the three best designs there will also be ten honorable-mention awards of $100 each for the next best designs.

The competition opens Jan. 1, 1949, and closes June 30, 1949. Any engineer or designer who feels himself qualified to enter the Program is eligible for participation.

The bridge to be designed is a two-lane deck highway bridge supported on two end piers 120 ft. apart. The bridge is to be designed for A.S.T.M.-A7-46 steel and for H20-44 loading. While the size, steel and loading for the bridge are specified, other than these specifications—the designer is completely free to exercise his ingenuity. If he wishes, the designer may conceive and use new structural shapes not now available, providing only that the new shape or shapes can be readily produced if and when a demand for them develops. Moreover, he may assume availability of fabricating facilities other than those now in existence.

The Foundation, according to Dr. E. E. Dreese, Chairman of the Board of Trustees, wishes to give designers an opportunity, free from the present limitations and restrictions on design practice, to apply their knowledge and experience to the problem of designing a bridge expressly for arc-welded fabrication. It is felt that considerable progress in design will result when designers are not restricted to using the present structural shapes and fabricating methods which were conceived before welding was generally available.

The Rules and Conditions for the "Welded Bridges of the Future" Program have been reviewed and approved by a Rules Committee. This same Committee will also sit as the Jury of Award in rating the entries. The Rules Committee and Jury of Award is under the direction and Chairmanship of Wilbur M. Wilson, Research Professor of Structural Engineering, University of Illinois.

Complete details of the Rules and Conditions of the Program are available in a printed brochure which can be secured upon application from The James F. Lincoln Arc Welding Foundation, Cleveland 1, Ohio.

Worthington to Handle Ransome Line

Worthington Pump and Machinery Corp. announced that the manufacturing and distributing activities of its subsidiary, Ransome Machinery Co., have been conducted by the parent corporation since Nov. 29, 1948.

Manufacturing operations for the lines previously manufactured by Ransome are carried on at Worthington's Dunellen Works, Dunellen, N. J., the same location formerly used by Ransome Machinery Co. Sales activities are directed from Worthington's executive offices at Harrison, N. J., through the Ransome Sales Division located at the Dunellen Works.

Customers may be assured of attentive service with the benefit of the added facilities of the entire corporation for research and development, procurement, manufacture and marketing.

Mallory Receives Citation

A citation for "outstanding achievements in human relations in labor" was awarded to P. R. Mallory & Co., Inc., at the sixth annual Executive Leadership Forum, sponsored by the Indianapolis Junior Chamber of Commerce on November 16th.

This award was one of five made to Indianapolis firms by the Executive Leadership Forum for achievements in various phases of human relations.

P. R. Mallory & Co., Inc., manufacturers of electronic and metallurgical products, have long been leaders in the labor relations field. The most recent development in the Company's policy has been the adoption of a profit-sharing program. This plan has been in operation since June 1947, and has been eminently successful as indicated by improved morale, more job security, increased productivity, a greater degree of cooperation, an approved level of earnings.

The Mallory organization signed its first Union contract with the United Electrical Workers C.I.O. in 1937. Relations between the Union and the Company have been harmonious ever since. From the day the contract was signed, there has not been a single hour of time lost as a result of work stoppage.

The Mallory management has consistently pursued a liberal and far-sighted labor relations policy. Phillip R. Mallory, Chairman of the Board, and J. E. Cain, President, have both recognized the importance of the human side of business and have stressed that phase of the Company's activity in their direction of its affairs for many years.

Snow-Melting Highway

The dream of every motorist and every highway engineer—a snow-melting highway—is about to be opened for use in the town of Klamath Falls, Ore.

In the first application of radiant heating principles to a public road, the highway will be heated in bad weather by hot water from an underground spring circulated through a network of welded wrought iron pipe laid in the concrete. Four lanes wide, 450 ft. long with an 8% grade, this dangerous road area is designed to remain clear and skid-free in all weather by automatically melting up to 1 in. of snow or $^1/_{10}$ in. of ice per hour.

The stretch of all-weather heated pavement is on the Dalles-California Highway leading into Klamath Falls from the north. It passes under the Southern Pacific Railway viaduct and a few hundred feet farther crosses an irrigation ditch, thus necessitating a grade 2 or 3% steeper than would be normally used.

Work was started on the road late last spring after a 10-in. well had been drilled which struck a good flow of hot water at 390 ft. G. S. Paxson, bridge engineer for the Oregon State Highway Commission who developed the idea for the winter-proof highway, has announced that the stretch is completed and in operation.

The hot well-water itself is not run through the roadway piping. Instead, a coil of 2-in. pipe is submerged deep in the well-water, which tests at 190°, about 26° below boiling temperature. In effect, the well serves as a boiler. A pump sends ordinary water and antifreeze through the well coil, where it is heated or reheated to not less than 160°.

PROPER ELECTRODES MUST BE USED

TABLE IV · *Welding Electrodes—Clad Side*

(1) Cladding	(2) Cover Exposed Steel with 1st Pass or Layer	(3) Complete Balance of Weld with	(4) Alloy to Steel (Welds not Exposed to Corrosion)
405	25-20, 25-12, 18Cr[1]	25-20, 25-12, 18Cr[1]	25-20, 25-12
410	25-20, 25-12, 18Cr[1]	25-20, 25-12, 18Cr[1]	25-20, 25-12
14-16Cr	25-20, 25-12, 28Cr[1]	25-20, 25-12, 18Cr[1]	25-20, 25-12
430	25-20, 25-12, 28Cr[1]	25-20, 25-12, 18Cr[1]	25-20, 25-12
301	25-20, 25-12	25-20, 25-12, 19-9	25-20, 25-12
302	25-20, 25-12	25-20, 25-12, 19-9	25-20, 25-12
304	25-20, 25-12	25-20, 25-12, 19-9	25-20, 25-12
308	25-20, 25-12	25-20, 25-12, 19-9	25-20, 25-12
321	25-20Cb, 25-12Cb	25-20Cb, 25-12Cb, 19-9Cb	25-20, 25-12 25-20Cb, 25-12Cb
347	25-20Cb, 25-12Cb	25-20Cb, 25-12Cb, 19-9Cb	25-20, 25-12 25-20Cb, 25-12Cr
309	25-20	25-20	25-20, 25-12
310	25-20	25-20	25-20, 25-12
316	25-20Mo, 25-12 Mo	25-20Mo,25-12Mo,19-9Mo	25-20, 25-12 25-20Mo, 25-12Mo
"L" Nickel	Nickel	Nickel	Nickel 80Ni-20Cr, 25-20Cb, 25-12Cb
Nickel	Nickel, 80Ni-20Cr[2]	Nickel, 80Ni-20Cr[2]	Nickel 80Ni-20Cr, 25-20, 25-12
Monel Inconel	Nickel 80Ni-20Cr	Monel 80Ni-20Cr	Nickel 80Ni-20Cr, 25-20, 25-12

[1] Must be used under certain corrosive conditions.
[2] May be used under certain corrosive conditions.

There's a *preferred* type of electrode for welding the clad side of each Lukens Clad Steel. The corrosion-resistant surface must be continuous across the surface of the weld. The structural strength of the weld must be high.

Welding rods recommended to assure these properties are shown in this chart. Use any good grade of carbon steel electrode for welding the steel side.

Contamination or dilution of the weld metal by pickup of the backing steel is guarded against by the use of electrodes having higher analyses than the cladding material. Laying on a number of thin layers of weld metal also reduces contamination.

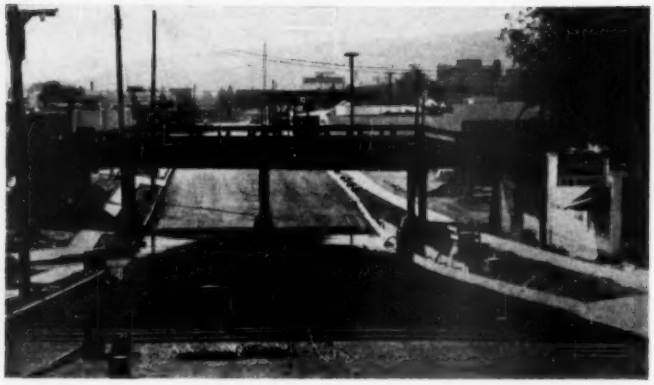
Lukens has made hundreds of experiments with welding electrodes. Our engineers have worked with those companies who are regular fabricators of Lukens Clad Steels. Electrode recommendations shown in this table are, therefore, based on experience. Lukens Steel Company, 407 Lukens Bldg., Coatesville, Pa.

CLAD METAL STEEL

LUKENS
Nickel-Clad Stainless-Clad
Inconel-Clad Monel-Clad
STEELS

SOLID METAL ADVANTAGES WITH CLAD STEEL ECONOMY

• • SPEED SCRAP TO THE MILLS TO MAKE MORE STEEL • •



These wrought iron pipe coils will keep a deep stretch of highway in Klamath Falls, Ore., clear of ice and snow this winter. Water heated in a natural spring circulates through the pipes

A 2-in. pipe runs from the well to the pavement, and then parallel to the road for a distance of about 400 ft. In the pavement slab are embedded 15,000 ft. of $^3/_4$-in. wrought iron pipe, made up into one grid for each of a series of 30-ft. road panels. Each of these 15 panels is connected with the 2-in. water main by valves.

The pipe carried a coating of asphalt before being laid in the concrete. Wrought iron was used in the installation because of its resistance to corrosion and because its coefficient of expansion is virtually the same as that of concrete, thus keeping the bond and minimizing the danger of cracking the concrete.

The 2-in. main and the series of grids compromise a closed circuit through which heated water is pumped, the valves insuring an even flow of water through each grid. Thus the whole 8-in. slab of road concrete is warmed to snow-melting temperature.

The pump, thermostatically controlled, automatically begins to circulate the water when air temperature drops to freezing and continues to operate until the temperature rises above freezing. Another pump draws water from the well since it loses its heat value as the cool water flows from the road through the heat transfer coils. Hot water then bubbles up from the earth back into the well.

This type of heating, with a boiler used to heat the water, has been increasingly popular in residential, industrial and business construction. During the past few years it as been brought outdoors in many installations to winter-proof sidewalks, airports, private driveways and filling station areas. A private road was opened last winter at Belmont, Mass., near Boston, and the American Cyanamid Co. plant at Bridgeville, Pa., has a 600-ft. long, two-lane driveway protected by embedded wrought iron pipe coils.

The natural hot water at Klamath Falls in Southern Oregon is widely used by the residents. It has been tapped to heat 400 homes, a swimming pool, two hospitals, a high school, a new office building, several apartments houses, business buildings and a newly constructed $3,000,000 veterans hospital. It is used for sterilizing dairy and soft-drink bottles. Ranchers outside of the town use it to heat their poultry sheds and green houses and to warm drinking water for their stock.

The town enjoyed hot mineral springs, once used by the Indians, until they dried up after the San Francisco earthquake of 1906. Geologists believe the water is heated either by hot underground lava or by chemical action.

Welded D. T. & I. Shops

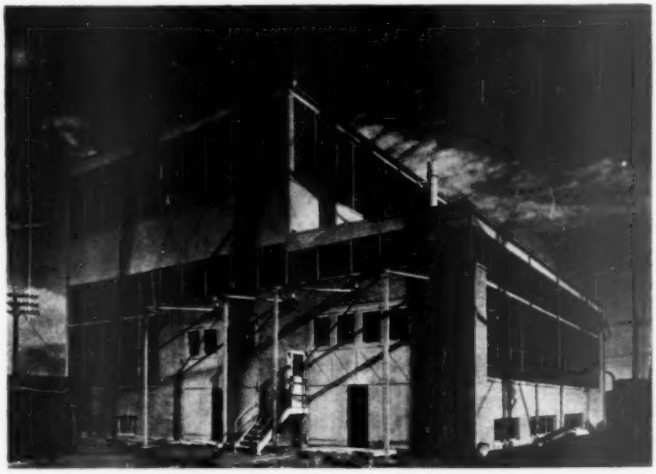
Innovations designed to reduce the cost of Diesel locomotive maintenance and to speed repair work in the interest of better freight service on the Detroit, Toledo & Ironton Railroad were viewed by executives representing the line's largest shippers early this month, following completion of the shops which were designed and built by The Austin Co. at Flatrock, Mich.

All the repair and maintenance work has been placed on a straight-line basis, where elevated tracks and mezzanine platforms at engine floor level afford easy access to all parts of engines under repair.

Two electrically operated lift bridges have been installed at one end of the building to enable members of the maintenance crew to cross over the open track area from one mezzanine platform to another without using any stairs.

Another unusual feature of the building is an exhaust system developed by Austin and D. T. & I. engineers for removal of fumes from the stacks of engines on test. A single motor-operated exhaust fan on the roof discharges engine fumes to the outside through a series of movable ducts, which can be swung into position and lowered over stacks at various points along the track.

The shops, 102 ft. long and 75 ft. wide, have a welded structural steel frame, face brick curtain wall and two bands of continuous ventilating sash separated by a band of asbestos cement siding. Clearance of 33 ft. under the crane has been provided above track level in the 50-ft. craneway bay, where a 25-ton welded crane, furnished by Northern Engineering Works, and four 50-ton Whiting hydraulic jacks have been installed. Rails (152 lb.) have been welded directly to posts set in a heavy reinforced concrete slab to form tracks which extend the length of the building in high and low bays at a level 3 ft. above the floor. Pits directly beneath the track are depressed another foot to enable men working on the trucks to perform their work comfortably.



This new diesel locomotive shop, designed and built by the Austin Co. for the running repair and overhaul of diesel locomotives on the D. T. & I. Railroad, has two tracks which extend right through the building. The high bay has a 50-foot span and accommodates a 25-ton traveling crane with 33-foot clearance above an elevated track

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"Standards" save Time. Standard Mallory Tips and Holders are on their way to you in 24 hours. When you order Mallory "standards" you eliminate the delay that special tools and fixtures require.

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PERSONNEL

District Manager Appointments

The Lincoln Electric Co. of Cleveland, Ohio, announces recent appointments and changes in its District Managers.

C. W. Lytton has been made District Manager for the Buffalo, N. Y., area. His office is located at 1700 Niagara St., Buffalo, N. Y. Mr. Lytton has had a broad experience in the field with Lincoln Electric, starting with the company shortly after his graduation from Case Institute of Technology in 1931 with a degree in Electrical Engineering. After a short term of work in the factory, Lytton was sent to the Lincoln Pittsburgh office, first as a service man and shortly thereafter became a sales engineer. In 1934 he was moved to Oil City, Pa., to act as District Manager of the northwestern Pennsylvania district. In 1942 this office was moved to Franklin, Pa., where he remained until his appointment in Buffalo.

C. M. Richardson has been appointed District Manager for the northwestern Pennsylvania district for The Lincoln Electric Co. His office is located at 741 Liberty St., Franklin, Pa.

Mr. Richardson is also a graduate of Case Institute of Technology, graduating in 1936 with a degree in Mechanical Engineering. He went to work for The Lincoln Electric Co. immediately following graduation and has been engaged in sales engineering for the past twelve years in Ohio, Wisconsin, Illinois, Iowa and Buffalo, N. Y. In 1942 he was made District Manager at Toledo, Ohio, where he had been for the past six years. While in Toledo, he was on the staff as a lecturer at the University of Toledo.

Ray Zeh has been appointed District Manager of the Toledo, Ohio, district for The Lincoln Electric Co. His office is located at 663 Spitzer Bldg., Toledo, Ohio.

Mr. Zeh graduated from Western Reserve University in 1937 and started to work that year for The Lincoln Electric Co. He worked in the factory for a year and a half in the experimental department and was then transferred to the sales engineering department. He has been active in the field for ten years in the Milwaukee, Wis., office. His recent appointment as District Manager in Toledo followed directly his service in Milwaukee.

All of these representatives are members of the AMERICAN WELDING SOCIETY.

Western Names New Works Manager

F. W. Dye, president of Western Supply Co., Tulsa, manufacturer of heat transfer equipment, has announced the appointment of Willard A. Emery as the firm's new Works Manager. The appointment of Emery, according to Dye, further augments Western's rapidly expanding manufacturing program, now serving the petroleum, gas and chemical processing industries.

Willard A. Emery

Prior to joining Western, Emery was Assistant Plant Manager of the Worthington Pump and Machinery Corp.'s Holyoke Works, having served with that organization for 25 years. During that time, he held the positions of Sales Service Engineer, Production Manager, Superintendent of Welding and Refrigeration, Assistant Manager of Ordnance Division and Assistant Plant Manager, in the Worthington Holyoke and Harrison, N. J., plants.

A graduate of Massachusetts Institute of Technology, with a B.S. in Mechanical Engineering, Emery studied Business Administration at Rutgers University, and Welding Metallurgy at Brooklyn Polytechnic Institute.

Long active in professional and engineering circles, Emery helped to organize the Northern New Jersey and Western Massachusetts sections of the AMERICAN WELDING SOCIETY. He also served on the Board of Directors of the Western Massachusetts Technology Club, and on the Advisory Committee of the Holyoke Trade School.

Poe Made Sales Manager

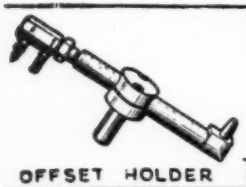
The appointment of Roy W. Poe as Sales Manager of Tweco Products Co., Wichita, Kans., is announced by R. L. Townsend, partner and general manager of the firm. Poe has had more than ten years in the field of sales promotion and advertising. He spent five years in the sales promotion department of the Kansas Gas & Electric Co. and was in charge of Sales Promotion and Personnel for the Swallow Airplane Co. for three years.

Roy W. Poe

Poe joined Tweco Products early in 1948 and in his new capacity will serve as sales and advertising manager working directly under the general manager. He will have his headquarters at the factory located at English at Ida Sts., Wichita, Kans.

Practical Welder and Designer

The Editor needs the help of all members of the AMERICAN WELDING SOCIETY in preparing interesting material for the Practical Welder and Designer section. If you have a short story for this section please send it to the Editor of THE WELDING JOURNAL, 33 West 39 Street, New York 18.



PAGE WELDING ELECTRODES AND GAS WELDING RODS

WELDING STAINLESS?

○

TO RESIST WHAT?

HEAT?
COLD?
IMPACT?
BENDING FATIGUE?
CORROSION?
WHAT **KIND** OF CORROSION?

○

NOW ONE MORE QUESTION:

Are you using the best electrode or rod for your purpose?

If you're not too sure, get in touch with your PAGE distributor. Either he knows or he can find out from the PAGE Field Service Man. And the PAGE distributor has a wide selection of Page-Allegheny Stainless Steel rods and electrodes, so that he can give you the one that will serve you best.

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NEW LITERATURE

Brazing Flux

Master Laboratories, 1545 N. Artesian Ave., Chicago, Ill., has issued a leaflet on master flux and metal conditioner for brazing or welding, which it is claimed, restores strength and toughness into the area adjoining the weld.

Welding High-Strength Aluminum Alloys

New findings on the welding of high-strength aluminum alloys are described in a report just released by the Office of Technical Services of the Department of Commerce.

Three approaches to the improvement of welded joints are discussed in the report: (1) the development of improved filler metals; (2) the effects of various heat treatments and (3) the use of unorthodox joining methods including cold-pressure welding. While work on the two first approaches remains far from complete, promising leads appear to have been uncovered. Unorthodox welding techniques on the other hand, do not yet seem to offer definite hope for improving the quality of welded joints.

As part of the study carried out by the Battelle Memorial Institute for the Department of the Army, determinations were made of the strength properties of joints in thick high-strength alumimum alloy plates, welded by conventional processes with currently available filler materials. These results are available in essentially complete form.

Conventional welded joints were found to have only from 5 to 30% of the ductility of the parent plates, emphasizing the need for filler-rod alloys that would deposit more ductile weld metal. A few tests completed with "Alcoa 716" filler rod showed consistently superior results to those obtained with 438 filler rods, or alloys of identical composition to the parent metal.

Tensile efficiencies of welded joints were found to be markedly improved by full heat treating. No work as yet has been done to determine possible advantages of mechanical working welds to improve joint efficiencies.

PB 92831, *Investigation on the Welding of High-Strength Aluminum Alloys*, 63 pages including photographs, tables and charts, can be obtained in photostat form for $8.75, or in microfilm form for $3.00. Orders should be addressed to the Library of Congress, Photoduplication Service, Publication Board Project, Washington 25, D. C., accompanied by check or money order payable to the Librarian of Congress.

Jigs and Fixtures

Jigs and Fixtures, 5th ed., by Fred H. Colvin and Lucian L. Haas. Published by McGraw-Hill Book Co., 330 W. 42nd St., New York 18, N. Y. Price $4.50. This standard guide provides information covering all aspects of the design and use of jigs and fixtures. It answers your questions on what is standard practice in large shops and shows how you can adopt these practical methods for your own use. Standard data have been brought up to date and new material added on jigs and fixtures for various machining operations. Each item entering into the proper design of jigs and fixtures is given careful attention, such as arrangement of views, lines and line work, dimensioning, screw-thread representation for bolts and threaded parts, etc.

Hard Facing Tire Chains

Wall Colmonoy Corp., 19345 John R. St., Detroit 3, Mich., recently published a two-page Data Bulletin describing the procedures for hard facing tire chains. Complete information on procedures, equipment and material required is outlined.

Tire Chains hard faced as described will last more than $3^1/_2$ times the life of unfaced chains.

Advantages of Low Heat Welding Technique

A new, completely illustrated eight-page bulletin presents the advantages of and reasons for selecting the low-heat-welding alloys manufactured exclusively by the Eutectic Welding Alloys Corp., New York 13, N. Y. for new welding jobs.

This Sept.-Oct. issue of the *Eutectic Welder* will be received by more than 250,000 engineers, technicians and welders in countries all over the world as well as in the United States. It stresses the many reasons for choosing low heat alloys for arc, torch and furnace application, and it presents complete case histories of eight difficult welding problems with pictures illustrating each. The solution for each problem is carefully explained and discussed so that the special advantages in selecting low heat welding can be easily seen and applied in similar cases.

A complete reference chart for the welding of all metals that shows the proper low heat alloys for every welding application is included in this issue.

This *Welding Method Selection* issue is available by writing to the Eutectic Welding Alloys Corp., 40 Worth St., New York 13, N. Y.

Bulletin on Inert Gas Welding

Inert gas welding, the process now uppermost in the minds of industrial welders large and small, as a business, or as an essential part of manufacture, receives an important contribution in a bulletin just issued by Fansteel Metallurgical Corp. The bulletin is most practical and helpful in its information to all who are using or contemplating use of helium, argon or atomic hydrogen arc welding, methods which are revolutionizing the welding industry. This includes the smallest setups for welding to the largest automatic as well as manual.

New advantages, new simplicity, new economies are found in this process. It is applicable to the widest range of welding—tanks, stainless steel fabrication, dairy, hotel and restaurant equipment, thousands of metal products big and little throughout industry.

Specifically the new Fansteel bulletin deals with the tungsten electrodes, vital factor of inert gas welding's success. Absolutely necessary for perfect and uniform character of the welding is arc stability. For this, purity of the tungsten is essential. Pure tungsten melts at 6152° F., the highest melting point of all metals. Its vapor pressure (0.000005 mm. at 4580° F.) is the lowest of all metals. It is these properties which make tungsten useful as an electrode material. Fansteel tungsten electrodes are 99.9+% pure tungsten. Beginning with premium wolframite ore, every step of the production of tungsten at the Fansteel plant is under the control of trained metallurgists and quality control engineers. Every electrode must pass rigid inspection for cracks, surface impurities, dimensional errors and other imperfections.

The Bulletin illustrates from actual photographs the uniform clean welds, without grinding or polishing, made by inert welding with Fansteel electrodes. Copies may be had by addressing Fansteel Metallurgical Corp., North Chicago, Ill. Ask for *Bulletin 1.102*.

Reprint on Heliwelding

A new reprint of an article on Heliwelding has been announced by the Air Reduction Sales Co., entitled "How to Use Helium Shielded Arc Welding" and written by H. O. Jones, Airco welding specialist. The article originally appeared in *American Machinist* and is being used by them as a special report to the metal working industry.

The article covers such topics pertinent to inert-gas, shielded-arc welding as basic features, welding currents, electrodes and gasses, scope of the process, equipment employed, process procedures and case histories covering specific applications of Heliwelding. The 16-page reprint is illustrated with 18 photographs and numerous graphs and charts.

For your free copy of "How to Use Helium Shielded Arc Welding" write Dept. 2328, Air Reduction Sales Co., 60 E. 42nd St., New York, N. Y., or the Airco sales office nearest you.

"WELD SECURELY"

Do YOU Specify your welding requirements this way?

Do you know what the welding requirements are for bridges, buildings, piping, storage tanks, pressure vessels or whatever your type of fabrication?

This information, necessary for solving your practical, every-day welding problems, will be found in the standards issued by the American Welding Society.

Are You

—a Designer?

—a Welding Engineer?

—a Welding Operator?

—or engaged in any other capacity as a Purchasing Agent, Salesman or Administrative Executive?

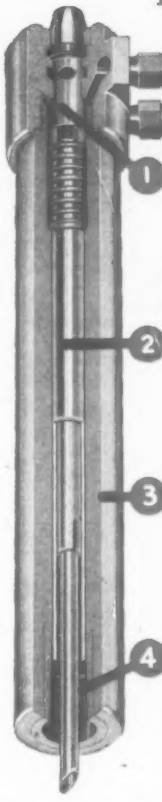
Then you should know what the material, filler metal, design, workmanship, inspection and qualification requirements are for different products and structures. You should be familiar with the standard welding nomenclature and welding symbols used in everyday welding conversation and correspondence, in technical articles and in contract specifications and regulatory requirements.

If you are not already familiar with the codes, standards and specifications of the American Welding Society as well as the educational books, ask the Technical Representative (Liaison Officer) of your Local Section for a free copy of Bulletin 101 describing these publications. Also ask about the special discounts to members. If you prefer, write directly to AWS Headquarters.

It is easy to keep informed through American Welding Society technical publications.

They will help you.
Use them!

water cooled *and positively* **LEAK PROOF**



(1) Hardened stainless steel knockout plug and leakproof water seal. Spring return assures free water ports and proper tip seating. (2) Non-rusting, non-magnetic knockout tube. (3) Strong, heavy body assures maximum conductivity, withstands heavy clamping pressure. (4) Hard alloy taper socket will not get out of round or leak.

WEIGER-WEED TRADE MARK

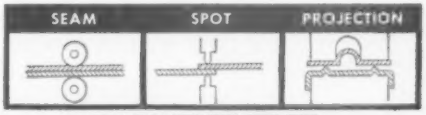
Heavy Duty

Welding Electrode Holders

Weiger-Weed Holders are designed to deliver more than enough cooling water for any resistance welding application using replaceable tips. And Weiger-Weed Holders positively do not leak at any water pressure which hoses and connections will withstand. When you put Weiger-Weed Holders on your machines, you put an end to cooling and leakage problems. Weiger-Weed Holders quickly pay for themselves in maintenance savings.

With these holders and Weiger-Weed Replaceable Tips, one can hardly help but reduce welding costs. And this same metallurgical quality and engineering forethought will be found in Weiger-Weed seam welding wheels, projection welding dies, flash and butt welding dies and special alloy bars, forgings and castings.

Weiger-Weed engineers and facilities are at your service to help you solve your resistance welding problems, whatever they may be. Weiger-Weed & Company, Division of Fansteel Metallurgical Corporation, 11644 Cloverdale Ave., Detroit 4, Michigan.



WEIGER-WEED TRADE MARK

Resistance Welding ELECTRODES
DIES • TIPS • WHEELS • HOLDERS
DIVISION OF FANSTEEL METALLURGICAL CORPORATION

Metco News

Metallizing saves money in the maintenance of pumps. The new easy-to-read, fact-packed November issue of the *Metco News*, tells you how it is done.

To help the readers solve their pump maintenance problems, the November issue of the *Metco News* shows the savings possible by metallizing a wide range of pump parts, both centrifugal and reciprocating.

One user of metallizing reports savings of $2,475 in one year. Another user reports a job involving bronze packing sleeves—replacement cost of new bronze sleeves was $44 each. Now they metallize these worn sleeves with stainless at a total cost of $6.70 each. The metallized sleeves outwears a new bronze sleeve by 4 to 1, giving this user a value of $176 for $6.70. Cost and time estimates are also given on many other applications.

Write for your copy of the *Metco News* and see how metallizing can help you. Ask for Volume 4, No. 5, Metallizing Engineering Co., Inc., 38-14 30th St., Long Island City 1, N. Y.

Literature on New Aircomatic Process

The Air Reduction Sales Co., has announced the availability of a six-page folder entitled "The Development of the Gas Shielded Metal Arc-Welding Process." Written by Jesse S. Sohn and A. N. Kugler and presented as a paper before the annual meeting of the AMERICAN WELDING SOCIETY, the article gives complete details and description of the new Aircomatic process which was introduced to industry at the National Metal Exposition.

Copies of this folder may be obtained free of charge by writing Dept. 2313, Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

Hard Facing Concrete Mixing Equipment

Recently published, a three page booklet, by Wall Colmonoy Corp., 19345 John R St., Detroit 3, Mich., describing the hard facing of mixer arms on concrete and cinder block equipment. It contains new complete information on hard facing procedures plus sketches showing exactly where to hard face the parts.

Increased life of 4 to 5 times has been reported from users of this equipment when hard faced as described in the booklet.

Welding Fundamentals

The objective of *Welding Fundamentals*, by H. P. Rigsby, is to present, in text form, a compilation of the fundamentals and principles of welding that will be useful to the engineering student.

Because the engineer is primarily interested in fundamentals, the actual technique of welding is of secondary interest to him, and it is so treated in this presentation. To learn welding as a vocation would require a great deal of time, several hundred hours of practice, and the engineer certainly does not expect or wish to master every manual trade that is related to his profession. However, a working knowledge of such trades will be of use in the practice of his profession and in dealing with the men who work at them.

Welding Fundamentals is published by the Pitman Publishing Corp., 2 W. 45th St., New York 19, N. Y. Price $2.75.

Phosphor Bronze Data Book

The Phosphor Bronze Corp. recently announced the publication of a new Technical Data Book. There are specific sections covering phosphor bronze strip and sheet, wire, rod, rope, castings, bushings, and ingots. Tabular data on the physical properties, chemical analyses, specifications and typical uses of the many analyses of this alloy, together with special spring design and machinability data, are included in this illustrated 28-page book. For your copy of the Technical Data Book write The Phosphor Bronze Corp., 2200 Washington Ave., Philadelphia 46, Pa.

BRAZING ALLOY SALES ENGINEERS WANTED

A large nationally known manufacturer of metal mill products is organizing a new Brazing Alloy Product Division.

Unusually attractive sales employment opportunities are open for qualified men on a salary and sales incentive basis.

Only applicants who have had experience in brazing or welding with proven sales ability will be considered.

Box No. 102, The Welding Journal, 33 West 39th St., New York 18, N. Y.

Buy "PROVEN FLUXES"
Years of GUARANTEED SATISFACTION behind these GOOD
"ANTI-BORAX" FLUXES

Insist on them — Unequalled Quality

No. 1 Cast Iron Welding Flux
No. 2 Brazing Flux for Brass, Bronze, Steel, etc.
No. 4 Braz-Cast Flux for Bronze Welding Cast Iron
No. 5 & 8 Cast & Sheet Aluminum Fluxes
No. 9 Stainless Steel Welding Flux
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No. 16 Silver Solder Paste Flux

Mfg. By
ANTI-BORAX COMPOUND CO., INC.
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SPOT WELDERS
OF ALL TYPES
SIZES 1/4 TO 300 KVA.
FOR MANUAL AIR, MOTOR, OR ELECTRONIC OPERATION
also BUTT, ARC, and GUN WELDERS

TRANSFORMERS
For Furnaces, Lighting, Distribution, Power, Auto Phase Changing Welding, and Special Jobs.
AIR OIL, and WATER COOLED.
Sizes 1/4 to 300 KVA.
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Time Counts—
Gas cut and Weld with
Shawinigan Carbide

SHAWINIGAN
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FOR TRIAL SAMPLE

LEARN WHY WELDERS CALL NI-ROD "THE EASIEST HANDLING ELECTRODE EVER MADE TO WELD CAST IRON"

In 1945, after several years of development and thousands of tests, The International Nickel Company introduced Ni-Rod* welding electrodes.

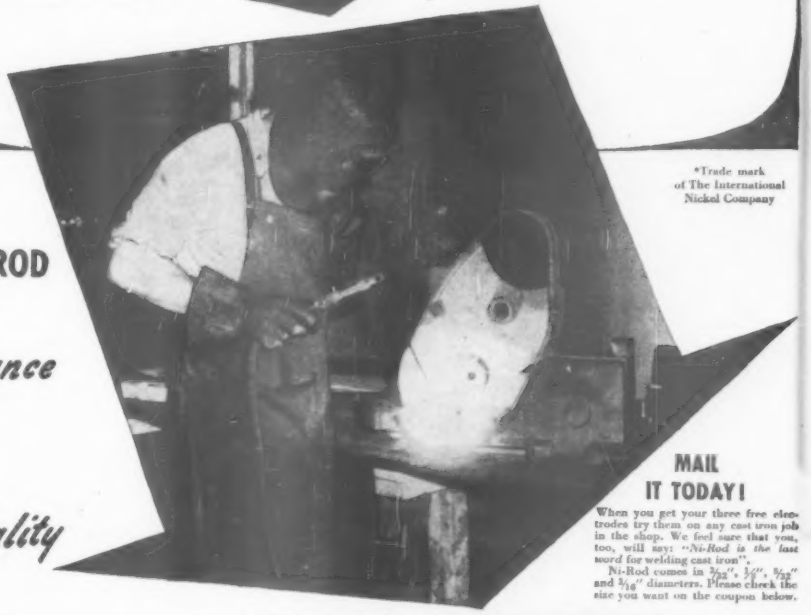
At that time we thought our laboratories had produced a rod that would finally take cast iron welding out of the "hit-or-miss" class.

Today, Ni-Rod has proven even better in the field than it did in the original tests.

Sales records show that 82% of our customers re-order Ni-Rod once they try it!

Welders keep telling us that Ni-Rod is the easiest-handling electrode ever made for welding cast iron.

And they're not only using Ni-Rod to weld cast iron. They're also using Ni-Rod to weld cast iron to steel.



*Trade mark of The International Nickel Company

HERE'S WHAT NI-ROD GIVES YOU

in performance

- Stable arc in all positions
- Smooth bead contour
- Excellent "wash"
- Easy slag removal
- Preheating seldom required
- Works on either a.c. or d.c.

in weld quality

- High-strength deposit
- Easy machinability
- Thorough fusion
- Freedom from cracks and porosity
- Close color match

in usefulness

- General repair and maintenance of cast iron parts, including the building up of worn surfaces.
- To remedy minor flaws in new castings
- For correction of machining errors
- As a production tool to assemble cast iron to steel

MAIL IT TODAY!

When you get your three free electrodes try them on any cast iron job in the shop. We feel sure that you, too, will say: *"Ni-Rod is the last word for welding cast iron".*

Ni-Rod comes in 3/32", 1/8", 5/32" and 3/16" diameters. Please check the size you want on the coupon below.

NI-ROD

Gentlemen: I'd like to try Ni-Rod welding electrodes. Please send me 3 free rods of the diameter I have checked.

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Company.....

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City..... *State*.....

EMBLEM OF INCO SERVICE NI-ROD TRADE MARK

THE INTERNATIONAL NICKEL COMPANY, INC.
67 WALL STREET • NEW YORK 5, N. Y.

How would you make SPOT WELDS

LINDE'S new HELIARC torch for making spot welds with contact from only one side.

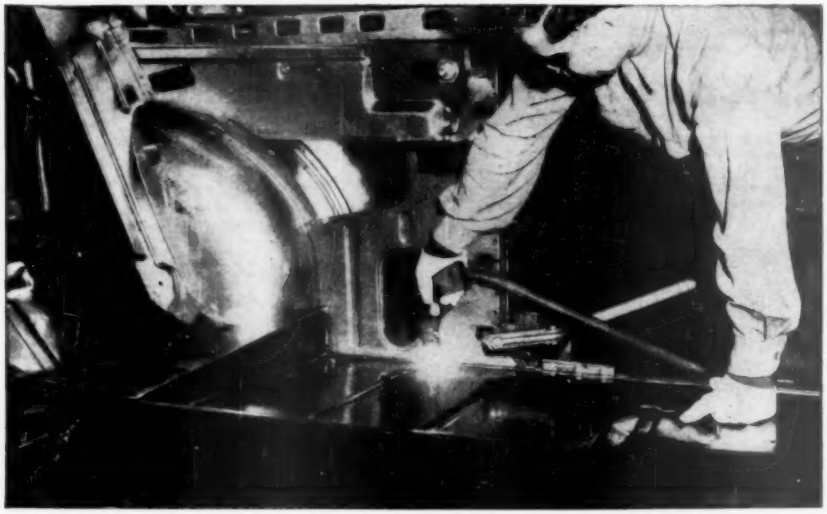
Net Weight ..... 2 lb.
Length (barrel) ..... 10 in.
Capacity ..... 250 amp.

One hose makes the spot welding torch as light and portable as an oxy-acetylene blowpipe.

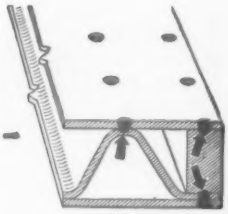
Trigger action

Push button control of electrode adjustment

With the HELIARC torch on the assembly line, you can easily make spot welds in those hard-to-get-at places. Other applications are just as easy.



IN PLACES LIKE THESE?



Full Scale

"HELIARC" TORCH SPOT WELDING can do it easily and quickly

Torch spot welding is a new use for inert-gas-shielded arc welding that fills a long-felt gap in sheet metal assembly methods. Spot welds are made by a light pistol-grip torch that requires access to the work from only one side.

Does many jobs

You can use this new HELIARC torch for many types of spot welding work. It is especially useful where the structure is large or of complicated shape because welding is done from one side and no forging pressure is required. You can spot weld ducts, tubes, containers, brackets, handles and many other assemblies. Mild steel, low alloy or stainless steel .030 to .064 in. thick are the metals that can now be welded. Not only can you join sheets of these metals in one to two seconds per spot, but you can also join a sheet of metal to underlying material of any thickness. Thus, corrosion resistant sheets can be spot welded to mild steel plate to provide cladding.

Easy to use

It's no trick to weld with the pistol-grip HELIARC HW-8 Spot Welding Torch. Just press the "muzzle" of the "gun" against the work and pull the trigger.

Low-cost power equipment is another feature of this process that makes it attractive. A regular 300 amp. welding transformer with high frequency unit is all that is needed to supply the power. Power return is by ground lead clamped to the work at any convenient location. A timer control automatically takes care of operating the accessory equipment.

Equipment is simple

Only one hose assembly connects the torch to the accessory equipment which can thus be placed out of the way to leave the entire work area free. The standard hose assembly is 25 ft. long. The hose is about an inch in diameter and contains conductors for power cable, cooling water, shielding gas, and trigger control. Electrode adjustment is easily made by push-button control located on the torch. All of these features make the spot welding torch easy and natural to use and as light and portable as an oxy-acetylene blowpipe.

The ease of use and quality of work done with HELIARC torch spot welding makes it an ideal production line tool. Contact any LINDE office for additional information about this new spot welding process.

The words "Linde" and "Heliarc" are registered trade-marks of The Linde Air Products Company.

Linde
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In Canada: DOMINION OXYGEN COMPANY, LIMITED, Toronto

NEW PRODUCTS

New High Silver Brazing Alloy

A new high-silver alloy specially developed to supplant regular silver brazing alloys through better performance and lower cost is now available to the welding industry. Eutectic Welding Alloys Corp., announces the availability of its new Eutecrod 1700 for stainless steel, copper, brass, bronze, tungsten carbide and steel.

Eutecrod 1700 is an unusually "thin-flowing" high silver alloy designed particularly for large scale production runs. It gives a much better color match to stainless steel and it is particularly recommended for making lap, square, butt and T-joints and for sealing and filling small cracks and defects. Eutecrod 1700 gives excellent results in joining tungsten carbide tips to steel shanks and in welding light gage metal as well as in the joining of stainless steel and in the welding of steel to steel or to other metals.

Eutecrod 1700 bonds at 1020–1250° F. and has a tensile strength of 64,000–68,000 psi. It is available in $^{3}/_{32}$, $^{1}/_{16}$, $^{3}/_{64}$, $^{1}/_{32}$ and $^{1}/_{64}$ in. diameters. Eutector Flux 1700 is a new high performance flux for use with Eutecrod 1700 to insure lowest heats of application.

For additional information, write to Eutectic Welding Alloys Corp., 40 Worth St., New York 13, N. Y.

Hastelloy and Multimet Alloy Available in Wire Form

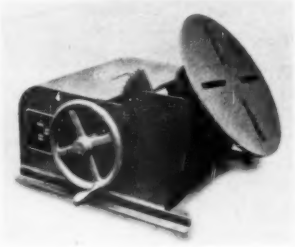
Hastelloy and Multimet alloy drawn wire—for welding, metal-spraying, and the manufacture of wire screen, wire cloth and springs—is now available in sizes down to 0.060 in. in diameter from Haynes Stellite Co., Kokomo, Ind. The wire is furnished in coils or in cut and straightened lengths, either bare of flux-coated. Sizes below 0.060 in. in diameter are supplied by an associate company, Kemet Laboratories Co., Inc., Madison Ave., and W. 117th St., Cleveland, Ohio.

Hastelloy alloys are high-strength, nickel-base alloys, that were specially developed to resist severe chemical corrosion. They withstand the action of the common mineral acids—such as hydrochloric and sulphuric—over a wide range of temperatures and concentrations, and also oxidizing agents such as ferric chloride and wet chlorine. Alloy B, which contains nickel, molybdenum and iron, is particularly resistant to hydrochloric acid; alloy C, a nickel-molybdenum-chromium-iron alloy, is specially suitable for applications involving oxidation. Both grades have excellent physical properties and exceptionally good high-temperature properties.

Multimet alloy is composed of cobalt, chromium, nickel and iron. It was developed specially for use at elevated operating temperatures. In addition, it possesses excellent physical properties and is comparable in tensile properties to high-strength steels.

New Work Positioner

A newly designed motor-operated work positioner, driven by an hydraulic variable speed transmission and a $^{1}/_{2}$ hp., single-phase a. c. motor, has been introduced by Ransome Machinery Co., subsidiary of Worthington Pump and Machinery Corp., Dunellen, N. J. The positioner, known as Model I-P, has a load capacity of 100 lb. By its use, production is increased up to 50% because all welds are made in the down-hand position.



The table top on Ransome's Model I-P rotates 360° at variable speeds, adjustable from 0–5 rpm. in either direction. It is manually tilted through 135° and locks at any degree of tilt by means of a worm-and-segment.

Ransome's Model I-P is ideally suited for such operations as welding, hard surfacing, assembling, repairing, grinding and similar operations because it places the work in a position most convenient for the operator.

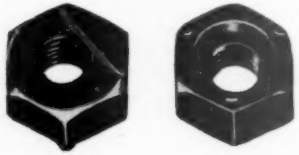
For full details and specifications, write Ransome Machinery Co., Dunellen, N. J., for *Bulletin 224-P*.

New Lock Nut, Weld Nut Combination

Where the application of nuts to bolts in production work is difficult due to lack of space, or where metal sections are too thin to thread, it is becoming common practice to use projection weld nuts. The application process is then reversed, the nuts are welded in final position and the bolt is screwed into the nut.

A similar practice is followed in anchoring bulky or heavy products to shipping cases, frames or boxes. The weld nuts are welded to the product, and bolts passing through holes in the container are screwed into the weld nuts to hold the product securely in position during handling and transit.

Trouble has frequently been encountered in the nut-welding process by particles of welding metal dropping into the nut threads during the welding process, requiring retapping of the nut. This trouble has been overcome in the Gripco 3-point projection weld nut,* by counterboring the bottom of the nut about a quarter of the way through, causing metal particles to fall on the counterbored portion (which slants outward) instead of on the threads. The thickness of the Gripco Weld Nut is increased to compensate for the threads removed by counterboring, thread depth being the same as in a standard nut.



(Left) Gripco "double triangle" thread-locking feature; (right) counterbore in Gripco weld nut

The top of the Gripco projection weld nut is the standard Gripco "double triangle" thread-locking design. When the bolt is applied, it locks into the Gripco nut and is prevented from loosening.

The Gripco 3-point weld nut has three projections for welding contact, assuring firm, nonrocking electrical connections when making the weld. It is a product of the nation's oldest lock nut manufacturer, Grip Nut Co., 397-K, S. Michigan Ave., Chicago 4, Ill.

* Patented and patent pending.

Glove

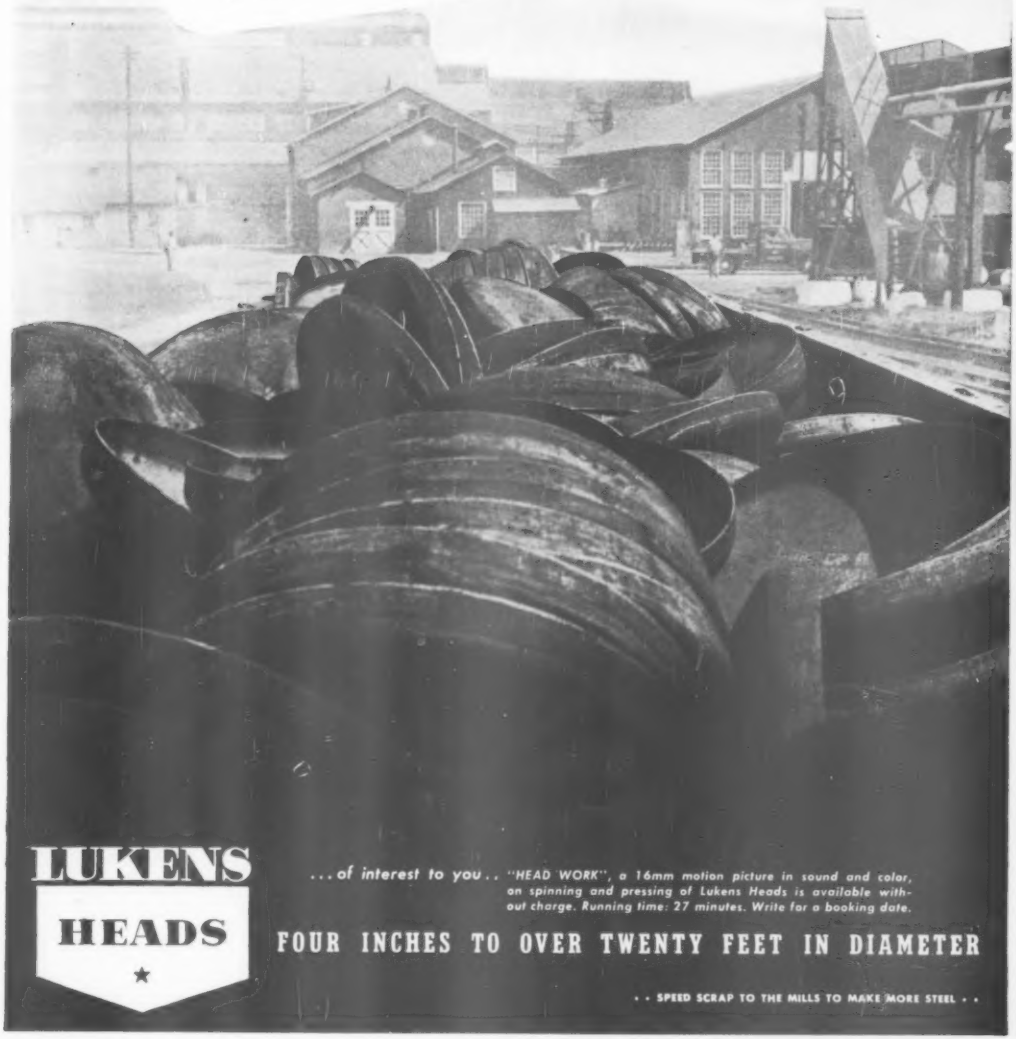
A new heavy-duty glove, ideal for handling small castings, rough stock, grinding and similar work has been added to its safety clothing line, American Optical Co., Southbridge, Mass., announces.

Made of specially treated chrome tanned cowhide for long wear, the glove features a canvas back with elastic strap to overcome hand fatigue while providing a cooler feeling and snug fit.

LUKENS HEADS

ANY SIZE · ANY STYLE · ANY MATERIAL

What heads do you need? Lukens can ship many sizes from stock and hundreds of dies are available for forming others. Write for prices and shipping dates, giving head diameters, gages, styles and materials. Lukens Steel Company, 407 Lukens Building, Coatesville, Pennsylvania.



LUKENS HEADS ★

. . . of interest to you . . *"HEAD WORK", a 16mm motion picture in sound and color, on spinning and pressing of Lukens Heads is available without charge. Running time: 27 minutes. Write for a booking date.*

FOUR INCHES TO OVER TWENTY FEET IN DIAMETER

. . SPEED SCRAP TO THE MILLS TO MAKE MORE STEEL . .

OPERATORS REPORT:

with G-E equipment...

The *proper model* of the *right type* of welder, with just the right electrodes and appropriate accessories to make YOUR welding job easier—and more profitable! That's the policy upon which the entire line of General Electric arc-welding equipment has been established, added to, and constantly improved, until today there is G-E arc-welding equipment for every welding application.

Take a-c welding, for example—*the most advantageous method for 75% of all welding applications.* G-E a-c welders are available in three basic types and 10 different ratings, from 100 to 1000 amps . . . all featuring easier arc striking, better arc behavior, stepless current control, and unusually compact design. A steel-fabricating company told us: "G-E a-c welders give us better, faster welding . . . lower power costs, less maintenance."

Inert-Arc and atomic-hydrogen welders for welding "difficult" metals are included in the a-c lineup. (Bulletins No. GEA-4081; GEA-4930)

A-C WELDERS

HAVE YOU SEEN "ARC WELDING AT WORK"? This new, sound-color motion picture depicts clearly the design and production advantages inherent in the three basic types of arc welding. Ask your G-E Arc-welding Distributor—or mail the coupon tomorrow.

Dept. E672-94, Apparatus Department
General Electric Company, Schenectady 5, N. Y.

☐ I'd like to see "Arc Welding at Work"

☐ Send me bulletin numbers .....

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Name & Company .....

Address .....

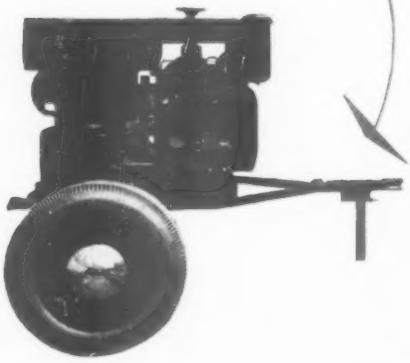
City ..... State .....

any welding job is easier...

D-C WELDERS

Sure, you can't beat d-c for certain welding applications! And for those jobs, you can't beat G.E.'s WD-40 line of d-c welding machines with their snappy, stable arc . . . single-dial dual control . . . 50% savings in size and weight . . . dependable, low-cost service over a long "life span." Available in 200-, 300-, and 400-amp ratings in motor-generator, belt-drive, or engine-driven models. "Smoothest machine we ever used!" say operators. (Bulletin GEA-4852)

This light-duty, trailer-mounted WD-3200BG welder (250-amp max. welding generator driven by a Wisconsin four-cylinder, air-cooled engine) has been making a tremendous hit. Mr. A. E. Poole, Vice-president of the Hallen Co. Inc., says: "This engine-driven welder is ideally suited for remote and difficult locations. It is rugged, yet light and easily maneuvered. And when you get it to those 'hard-to-get-at' jobs, it provides dependable operation with a peppy welding arc." (Bulletin GEA-4886)



ELECTRODES AND ACCESSORIES

67 types of G-E welding electrodes can help supply the answer for welding mild steel, cast-iron, stainless steel, phosphor-bronze—general purpose welding, and alloy and special-purpose welding; Bulletin GES-3571. G-E welding accessories, described in Catalog GEC-253, are designed for easier welding with maximum protection.

"A-C or D-C . . . there's G-E arc-welding equipment for every application!"

Copyright 1948, General Electric Co.

ARC WELDERS • ELECTRODES • ACCESSORIES

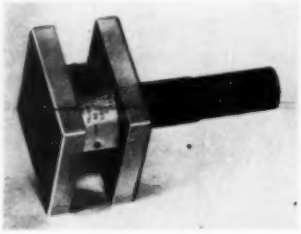
GENERAL ELECTRIC

All necessary seams are steel sewed and the seam along the forefinger has been eliminated for longer glove life and added comfort at this vulnerable point.

Wearing surface of the palm has been increased also, by extending the palm, and there is no bib patch—another comfort feature. In addition, the steel stapled strap at the thumb crotch fortifies this part of the glove. A steel stapled patch is on the face of the thumb. The glove also has a short cuff with tape binding.

Magnetic Ground

The Vanol Corp., 4170 Hartford St., St. Louis 16, Mo., announces a new magnetic ground under the trade name "Magnetrode." In addition to its function as a grounding contact, the magnetic action of the magnetrode is claimed to improve the quality of arc welding.



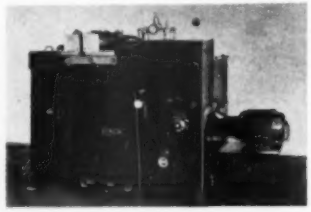
Advantages of the Magnetrode lie in its ability to reduce time and labor, magnetic blow, resistance, spatter and use less welding current, yet increase penetration. These and other advantages mark the Magnetrode as an interesting development in the field of electric arc welding.

The new unit is easily and quickly attached to the grounding cable, and can be used on all types and models of electric arc-welding machines, a. c. or d. c. Models vary for particular needs.

Magnetrode Model 700 is an all-purpose welding ground with four permanent magnetized faces for use on any round or flat surface. Model 700 has a capacity of 0–500 amps., and can be used on cables up to 4/0.

Hydraulically Operated Flash Welder

An hydraulically operated flashwelder that is completely automatic except



for loading and unloading is announced by Agnew Electric Co., Milford, Mich. It is identified as Type HAB. While the hydraulic pump supplies the pressure to actuate the movable platen and a flow valve controls the flash cycle—air is used for clamping. The dies are replaceable inserts which not only minimize die cost but also make practical a broad application of work. The tap switch on the transformer provides a wide heat range for diversified production. The machine is equipped with water-cooled 50-kva. transformer and clamps, welder-type magnetic contactor and all necessary pressure controls. The type HAB welder was particularly designed not only where a uniformity of welds is required, but also where close tolerances must be held.

Dual Head Welds 11-Ft. Tray in Six Minutes

Two Unionmelt welding heads, mounted on a single carriage as shown in Fig. 1, weld 1/8-in. thick side pieces to the perforated tray bottom 1/4 x 18 in. The electrical operating switches for both welding heads are mounted on one side for the operator's convenience. The carriage is mounted on a simple beam bridge that rolls over the fixture as shown in Fig. 2 and can be locked in position. Hydraulic pistons in the bridge and the fixture activate hold-down clamps. Copper strips beneath the joints on both sides of the tray back up the completely penetrated weld.

The Unionmelt electric welding process, permits the use of high welding currents and produces a clean uniform weld with complete penetration. By the use of this process the Silver Engineering Co. of Denver, Colo., is able to weld these trays in six minutes with no subsequent cleaning or chipping. Considerable savings are realized over other methods of fabrication.

Hydraulic Elevating Table

The Lyon-Raymond Corp. announces a new addition to its line of hydraulic elevating tables, the standard 4000-lb. capacity model.

This new table has a 30- x 30-in. top which revolves fully or can be locked in a fixed position. The top has a 14-in. range of elevation, the lowered height being 28 in. and the elevated height 42 in.

Two heavy-duty ball-bearing swivel casters and to heavy-duty rigid casters with 6-in. wheels and roller bearings provide portability under full load. A floor lock-type brake holds the table in position when required.

The single speed hydraulic foot pump developing 1000 psi. provides easy, smooth operation. A pedal release valve controls the lowering speed and holds the top securely at any intermediate position between the lowered and elevated heights.

Many other uses can be suggested for this new product. The range of elevation allows work to be positioned at a convenient working height for welding, grinding, die repairing and other bench jobs.

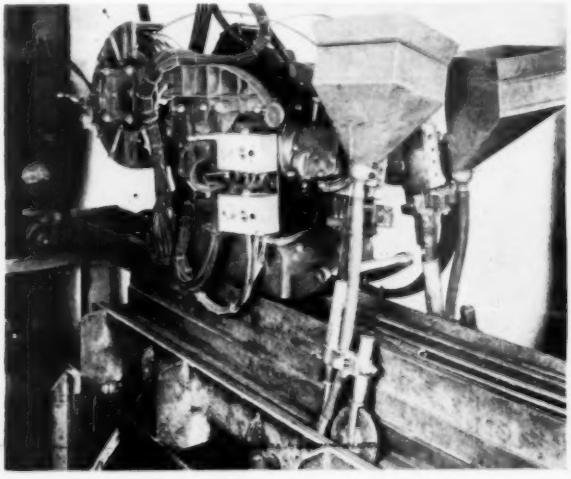


Fig. 1 Dual welding head on track beam bridge for tray fabrication

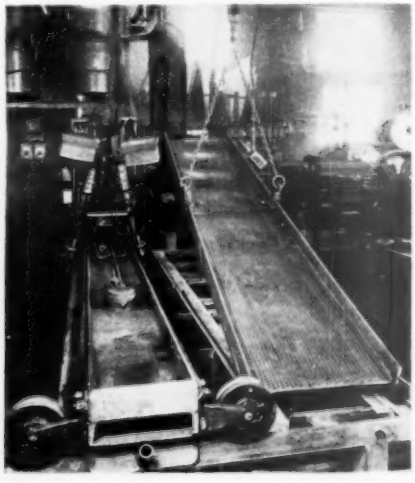


Fig. 2 Removing the finished tray

HAVING ANY DIFFICULTY

GETTING COPPER COATED WIRE IN REWOUND COILS FOR SUBMERGED ARC WELDING???

"RACO" RED LABEL is supplied in the following diameters: 1/16"—5/64"—3/32"—1/8"—5/32"—3/16"—7/32"—1/4". Wire is accurate in size and true round. Most beautiful copper coating in the industry. All sizes have a very light knurl to prevent slip in feed rollers. Coils are of any I.D. width, or weight. Thread wound to prevent tangling during feed off. Four grades—.06 car. max.—.08-.10 car.—.10-.15 car.—.13-.18 car. .95-1.25 mang. Small coils are rewound on fibre bands and wrapped on outside with heavy two-ply moisture proof paper. Write, telephone or wire for prices and deliveries. Be sure to state I.D. width and weight of coils desired.

HEADQUARTERS FOR ALL GRADES OF AUTOMATIC ARC WELDING ELECTRODES (COILS)

30 YEARS' EXPERIENCE IN FINE SPECIALTY WIRE DRAWING

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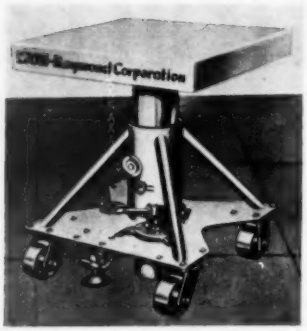
SINCE 1919 PRODUCERS OF ARC WELDING ELECTRODES AND WELDING RODS

TEL. Riverside 0566



Heavy overhanging work can be supported evenly because of the adjustable height. The unit can also serve as a modified sheet feeding table for handling heavy sheets.

Full information can be obtained from the Lyon-Raymond Corp., 6854 Madison St., Greene, N. Y.

Mill for Welding Water Tanks

A semicontinuous seam welding machine was designed and built by a West-Coast manufacturer* of hot water tanks for welding tanks of various diameters. Regulation of the welding current and the air pressure are the only adjustments necessary for welding tanks of different size. The longitudinal seam is made by the Unionmelt welding process, a method of welding electrically beneath a granulated welding composition which fuses in the welding zone and submerges the weld. The welds have complete penetration and are made without spatter. The fused composition detaches itself and reveals the smooth clean weld which does not require chipping or peening.

An operator forms the tank shells on pyramid rolls and feeds the cylindrical shells into the welding mill. A pneumatic ram forces each section against the preceding one and a chain drive moves the shells at welding speed beneath the welding head. A water-cooled copper shoe under the welding zone backs up the completely penetrated welds. The shells are fed through the mill on the lower flanges of an I-beam type support. Thus, shells from 8 to 48-in. diameter can be handled by the same fixture. After welding, the shells are taken by conveyor to the next station where the heads, bottoms and fittings are added.

With this machine, small lots of various diameters can be welded without shutting down the machine to adjust for each size of tank. The minimum diameter is determined by the size of the I-beam. Shells from 14 gage to $^3/_{16}$ in. thick can be welded in any succession. The machine is set to weld at 48 in. per minute and currents range from 400 to 550 amp.

* Southern Heater Co., Compton, Calif.

Cast Iron Electrode

The latest development in the welding of cast iron has been announced by Eutectic Welding* Alloys Corp., New York 13, N. Y.

Crack in the cast-iron base of this 40,000-kw. turbine was welded "cold" with the new EutecTrode 24/49

The new EutecTrode 24/49 has been specially developed to produce strong bonds and high tensile welds that are thoroughly machinable through the weld and the weld zone on both gray and alloy cast iron, without preheating.

This new electrode is applied at lowest currents to produce true low-heat welds. For example, the $^5/_{32}$-in. electrode welds cold cast iron readily at only 80–100 amp. It applies quickly and easily on a.c. or d.c. with either straight or reverse polarity. The welds have the ease of application and the smooth, sound appearance of those made with mild steel electrodes. The burn-off rate is uniform and the flow is rapid. The arc area is at all times clearly visible with this nonfuming rod.

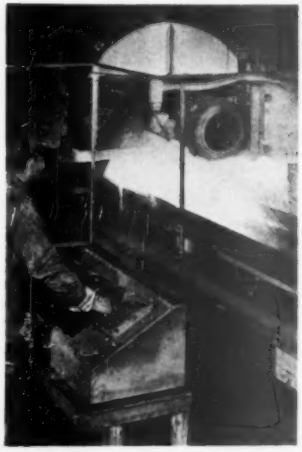
It is claimed that the simplified technique made possible with the new EutecTrode 24/49 makes every welder a cast iron welding expert, in repairing and salvaging anything from a delicate, intricate small casting, to the broken frames of huge presses.

EutecTrode 24/49 is specially recommended for the metal arc welding of gray and alloy cast iron where preheating is impossible or undesirable. Its excellent color match and complete machinability makes it ideal for cast iron repairs that must be finish-machined. It can also be used for making minor repairs on malleable cast iron, cast steel, nickel alloys and for the joining of any of these metals.

New Saw Melts Steel as It Cuts 13 Ft. a Minute

Built to exacting specifications, of United States Steel Supply Company engineers, to give quicker service to warehouse customers, the 60-in. blade is operated by

(*Continued on page 104*)



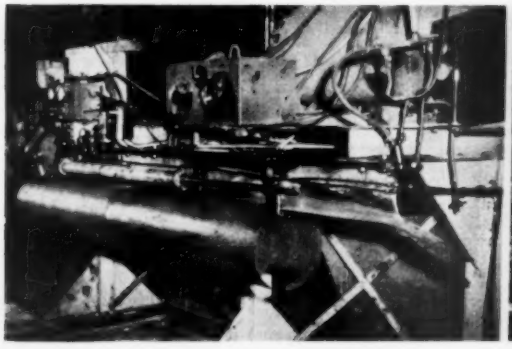


Fig. 1 Loading end of the continuous welding mill

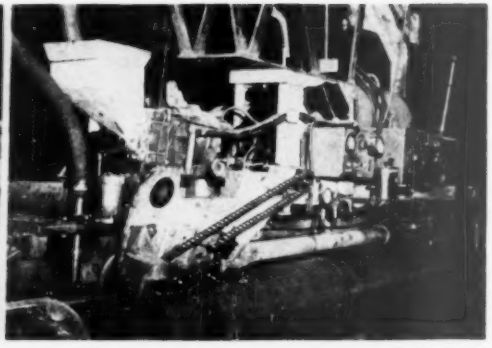


Fig. 2 A chain drive moves the shells at the proper speed beneath the welding head

Improved Ductility, Higher Resistance To Impact—

SMITHway

Coated

AC - DC

MILD STEEL

ELECTRODE

SW-17

SMITHway Mild Steel Electrode SW-17 is a general-purpose electrode designed for welding in all positions, with AC or DC straight-polarity current. SW-17 is specially adapted for poor fitup welding.

SW-17 is exceptionally suited for use where the desired physical properties include improved ductility and a higher resistance to impact. Especially recommended for use in welding road-building or similar equipment where toughness is required under severe operating conditions, and where low temperatures are encountered.

Made BY Welders...FOR Welders

Sold by Distributors Everywhere

PROVED IN PRODUCTION. A. O. Smith originated modern heavy-coated electrodes and modern welding techniques. Proof of SMITHway Electrodes has been given repeatedly in their huge production record. More than 320,000 have been used *daily* in A. O. Smith plants . . . millions more, by other manufacturers.

SMITHway AC WELDERS

Under most severe operating conditions, SMITHway Welders stand up under treatment that punishes other machines. Practically no maintenance is ever required. Power cost is cut to a minimum. Heavy-Duty, General-Purpose, and Utility Models. Send the coupon!

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SECTION ACTIVITIES

Prepared by C. M. O'Leary

Birmingham

J. Lyell Wilson, Director of Research, American Bureau of Shipping, was the speaker at the regular monthly meeting held on November 4th at Hooper's Cafe, Birmingham. J. Lyell Wilson has been associated with the American Bureau of Shipping since 1916. He has been associated with welding since its introduction to the shipbuilding industry during World War I. Mr. Wilson presented an interesting talk on "Inspection and Quality Control of Welded Construction."

A social hour and dinner preceded the technical meeting.

The December dinner meeting was held on Thursday evening, December 2nd, at Hooper's Cafe.

Fifty-five members and guests attended the regular social hour from 6:30 to 7:00. Fifty-six were present for the dinner at 7:00 and the technical session that followed at 8:00 p.m.

The technical speaker of the evening was A. Leslie Pfeil, President of the Universal Welder Corp., who spoke on "Resistance Welding and Its Jigs and Fixtures." A film, "Resistance Welding," was shown in conjunction with the talk. Much interest was shown in Mr. Pfeil's talk and many questions were asked following the talk.

Boston

New Developments in the Heliarc Process of Welding was the subject presented by James R. Craig, Supervisor of Process Service for The Linde Air Products Co., at the November 8th meeting held in Room 4-370, M.I.T. In covering the newer developments of the process, two important aspects comprised the major portion of the discussion. One of these is on hard facing with a Heliare process and the other on Heliarc-torch spot welding. Slow motion pictures of the arc in the inert gas atmosphere were again shown. There were also other illustrations in connection with the talk.

J. G. Magrath, Executive Secretary of the A.W.S., was also present and addressed the meeting briefly.

Dinner was served at Walker Memorial.

Bridgeport

Regular monthly dinner meeting was held on November 18th at the Candlelite Restaurant. R. T. Gillette, Welding Engineer of the General Electric Co., Schenectady, N. Y., spoke on Resistance Welding. A film on the same subject was also shown as well as a display of Resistance Welded samples.

The attendance was very good and the speaker held the attention of the entire group. The picture shown was excellent both from an instructive point of view and for general interst.

Chattanooga

December dinner meeting was held on Friday, the 3rd, at the Chattanooga Golf and Country Club. Refreshments were served before the dinner. "Maintenance Welding" was the subject presented by C. C. Keyser, Welding Engineer, Bethlehem Steel Co., Steelton, Pa. Mr. Keyser has been with the Bethlehem Steel Co. eleven years in the welding field. His talk was nontechnical, covering applications of the different types of welding in the steel plant with special emphasis on application of the submerged-arc process to maintenance work. Slides illustrated the talk and were described in an informal manner.

Chicago

"Welding of Corrosion and Heat Resistance Metals" was the subject of a paper presented by Paul Gordon Parks, Welding Engineer, Solar Aircraft Co., Des Moines, Iowa, before the Chicago Section at its November 19th meeting. Mr. Parks presented an interesting discussion of the welding of heat corrosion resisting alloy with particular reference to their applications in the aircraft industry. While much of the paper was confined to various resistance welding applications in this field, arc, gas and inert arc welding of stainless steel, Monel and Inconel were also discussed. It was pointed out that the advent of jet propelled aircraft and the continual demand for greater power from super-charged reciprocal engines has created an ever increasing use of high temperature alloys.

Prior to the meeting many members of the Chicago Section met at Burke's Grille and Restaurant for the prior meeting dinner.

Cincinnati

A joint dinner meeting of the American Society for Metals, the American Foundrymen's Society and the Cincinnati Section of the A.W.S. was held on November 11th in the Engineering Society Headquarters. George P. Stimpson of the Cincinnati Times-Star was the dinner speaker. Mr. Stimpson presented an interesting talk on "Our Cincinnati Weather" which was well received.

Charles W. Briggs, Technical and Research Director, Steel Founders Society of America, spoke at the technical session on "Cast Weld Construction," which was illustrated with 16-mm. slides. One hundred and sixteen members and guests were present at the technical meeting. Mr. Briggs' talk was good, clear cut and of interest to the executive and engineer.

Cleveland

John H. Blankenbuehler, Design Engineer of the Hobart Brothers Co., Troy, Ohio, spoke at the November 10th meeting held in the Cleveland Engineering Society. His talk was on "Power Supply for Heliarc Welding."

Mr. Blankenbuehler has had twenty-five years' experience in designing welding equipment, having spent twenty-three years at Westinghouse Electric Corp. and going from there to Hobart Brothers.

The Coffee Speaker was Dick Newpher, Division Manager of The Reliance Electric & Engineering Co., who described the "1948 Newport News to Bermuda Sailing Race."

There was an attendance of 100 at the meeting.

At the December 8th meeting the technical speaker was Leon C. Bibber, Welding Engineer at Carnegie-Illinois Steel Corp. in Pittsburgh.

Mr. Bibber spoke on "The Effect of Welding and Other Local Heating Processes on Residual Stress and Dimensional Changes in Steel." He discussed the principles involved in the shrinkage of steel as a result of torch cutting, residual stress, warping, distortion and methods of correcting the latter.

J. Frank Maine, Chief Engineer of the Republic Structural Iron Works, spoke at dinner. Mr. Maine is Past Chairman of the Cleveland Section and takes an active part in national affairs. He is also a traveler of some note in this country and showed a great many beautiful colored pictures in connection with a travelog on an extended tour of the western states.

Colorado

November 9th meeting of the Colorado Section was held in the Range View Room, Silver Wing Inn, Denver. Speaker at the technical session was Roy O. Schiebel, Jr., Mgr., Magnaflux Corp., who spoke on "The Importance of Testing Welds." There was a very fine turnout for a splendid speaker on an interesting subject.

Columbus

1948 All-Council Meeting with Columbus Technical Council was held on Friday.

November 12th, following dinner at the Southern Hotel.

Principal speaker was Dr. E. U. Condon, Director, National Bureau of Standards, Washington, D. C. His subject was "Research at the National Bureau of Standards." A very interesting and informative talk.

Opening event at 4 p. m. was a panel discussion. Delmar G. Starkey, Executive Secretary of the Chamber of Commerce, was the Moderator. Subject of the panel discussion was "The Growth and Development of Metropolitan Columbus—Its Technical Aspects." Panel members were: A. P. Harness, Philip Burgess, Perry Shumaker, Harry Turner.

A social hour from 5:30 to 6:30 was held preceding the dinner in the main ballroom.

Program of meetings for 1949 are as follows:

January 14th—Joint Meeting with American Society for Metals. Robert Aborn, United States Steel Corp. will speak on "Metallurgy of Ferrous Welding."

February 11th—Orville T. Barnett, Metal & Thermit Corp., will speak on "Electrode Classifications."

March 11—Leon C. Bibber, Carnegie-Illinois Steel Corp.

April—O.S.U. Conference.

May—Tenth Anniversary Night.

Dayton

Regular monthly meeting was held on Wednesday, November 17th, at the Engineers Club. Harold Baldwin, of the R. G. LeTourneau Co., talked on "How to Figure Welding Costs."

Detroit

Four experts on inert-gas-shielded arc welding discussed equipment and newly developed processes in this rapidly growing field at the November 12th meeting held at The Engineering Society of Detroit.

H. T. Herbst, Manager, Heliarc Division Laboratory, The Linde Air Products Co. discussed apparatus and methods for the heliarc process.

Emery Lee, Regional Manager, Detroit Office Federal Communications Commission, presented latest information on radio and television interference caused by arc welding, and R. F. Wyer, Application Engineer, Welding Division, General Electric Co., and W. E. Coules, Equipment Section, Pittsburgh Works, General Electric Co., discussed and showed slides on electrical characteristics of inert arc welding.

The Saginaw Valley Division held its regular monthly meeting on Thursday, November 11th, at Zehnder's in Frankenmuth. The same four speakers who spoke at the Detroit Section meeting the following night were scheduled for this meeting.

A movie "Microtime," slow-speed pictures of milling cutters, etc., in operation and an animated picture of the action of Stainless Steels in Resisting Corrosion, were shown through the courtesy of The Allegheny Ludlum Steel Corp.

Hartford

A talk and demonstration on inert-gas-shield arc welding was made on Thursday, November 18th, at a dinner meeting held in The Whitlock Mfg. Co. J. R. Craig, Engineer for The Linde Air Products Co., was the speaker. A high-speed film showing Arc characteristics was also shown. An attendance of 85 members and guests enjoyed the various activities.

Indiana

Monthly meeting was held in the Delco-Remy Plant in Anderson, Ind., Friday, November 19th, with a dinner in their cafeteria. A very interesting trip was taken through two of their nine plants. An attendance of 75 saw the complete manufacture of automotive generators, voltage regulators and relays. A technical session was held after the plant tour in which C. A. Nichols, Master Mechanic for Delco-Remy, discussed the products manufactured along with special processes developed in conjunction with their manufacture.

An interesting training film on silver brazing was shown by Paul Feld of Handy and Harman, with a discussion on silver brazing following the film showing.

Lehigh Valley

A. N. Kugler, Technical Sales Division, Air Reduction Sales Co., was the guest speaker at the monthly meeting of the Lehigh Valley Section, which was held Monday, December 6th, at Fritz Engineering Laboratory, Lehigh University, Bethlehem, Pa. C. L. Kreidler, Chairman, presided.

Mr. Kugler gave a very interesting talk on the "E60XX Series Electrodes." He discussed the color code used in making electrodes, the meaning of the A.W.S. classification and the uses for each type of electrode. Following the talk there was a demonstration of the proper technique to be used for all the electrodes in the E60XX series, under the direction of Russell Strate, Air Reduction Sales Co.

A dinner meeting in Lamberton Hall, Lehigh University, preceded the technical session.

The following is the program for the remainder of the season of the Lehigh Valley Section.

All meetings are to be held at the Hotel Bethlehem, Bethlehem, Pa., with the exception of the February meeting.

February 7th—Demonstration of the General Electric Automatic Welding Head at Fritz Engineering Laboratory, Lehigh Univ.

March 7th—"Welding Metallurgy" by R. D. Stout, Lehigh University.

April 4th—"Future Developments in Welded Steel Buildings" by A. Amerikian, Navy Dept., Bureau of Yards & Docks.

May 2—Annual Meeting.

Los Angeles

Thursday evening, November 18th, the Los Angeles Section held its regular monthly dinner meeting jointly with the American Society of Metals. The speaker was Dr. Samuel L. Hoyt, Technical Advisor of Battelle Memorial Institute, Columbus, Ohio, and author of many technical papers and several books on metallurgy. Dr. Hoyt spoke from the welding engineers viewpoint on the subjects of "Hardenable Steels and Their Welding Functions" and "Notch Sensitivity Tests." Conclusions presented were the result of extensive research programs. Hardenable steels were discussed with respect to cracking sensitivity and the mechanism of hydrogen in cracking. Functions of low hydrogen electrode and preheating to disperse austenite was explained. Notch sensitivity tests were discussed with respect to their indicating plate brittleness. Development of notch brittle plate due to chemical and physical properties was described. In conclusion, Dr. Hoyt gave an enlightening explanation of the factors involved in testing notched plates.

Louisville

Robert H. Bennewitz, Process Service Supervisor, Detroit District, The Linde Air Products Co., was guest speaker for the November 23rd meeting at the Preston Kunz Restaurant. Mr. Bennewitz spoke on "High Production Applications of the Heliarc Process on Mild Steel."

The speaker explained that the Heliarc process can be used on almost all metals and alloys with but few exceptions. For mild steel it is especially applicable where a smooth weld finish and freedom from distortion are essential. The newly developed Heliarc spot welder is being used in the automotive industry for fusion welds on thin sheets without any backing.

The talk was illustrated with slides and in the discussion that followed, Mr. Bennewitz ably answered many questions from the audience.

The meeting closed with the showing of a color and sound movies, "Pigs and Progress" furnished by the Reynolds Metal Co. The film showed the whole process of producing aluminum metal and many aluminum products.

A Dutch Lunch was then served.

Maryland

On November 19th, Harrison Sayre of the U. S. Naval Experiment Station was the speaker at the meeting of the Maryland Section held in the Engineer's Club, Baltimore. Through the use of slides and detailed description, Mr. Sayre very interestingly discussed the reasons for warpage and distortion, the relationship of warpage and distortion to joint design, and finally, methods or measures to reduce the extent of the warpage or distortion. In the discussion period which followed the lecture, Mr. Sayre pointed out that it was frequently possible to assemble the members being fabricated to allow for the warpage or distortion that would take place thus ending up with a fabricated joint of proper shape.

The after-dinner entertainment was a showing of the interesting and very colorful travel pictures titled "Touring Louisiana."

"HOW I REPAIRED THIS CAST IRON PUMP OVERNIGHT— WITH NICKEL-ARC!"

BETWEEN PASSES, I let the work cool, because too much heat in any one spot on cast iron sets up thermal stresses which may crack the casting . . .

"It was easy to repair this broken cast iron pump with Nickel-Arc because it welds faster and smoother than any other rod I've used. Since using it for the first time, I've asked the welding superintendent to buy other Alloy Rods Co. electrodes because Nickel-Arc convinced me of their quality."

BILL WALNAZASKI

Suddenly the flange of a cast iron pump broke, shutting down a critical supply of water! The pump had to be in service again as soon as possible, and waiting for a replacement would have been too expensive, so the company welder was called in.

On this rush job, the welder chose Nickel-Arc because it would give him speed and a dependable weld deposit, and, in his own words: "I wanted the repairs to be right the first time." Overnight

Look for the

ABOUT 4 O'CLOCK I was called in to weld the flange back on a cast iron pump which had broken, cutting off one of the plant's main water supplies . . .

FIRST I CLEANED the break, then started to weld. I used Alloy Rods ⅛ inch Nickel-Arc for this work because it was a rush job, and I wanted the repairs to be right the first time . . .

THE WORK went fast and smooth, and after I was finished it was easy to clean the weld of slag; that's one of the many things I like about Nickel-Arc . . .

THE PUMP was put right back in service the next day. Nickel-Arc had saved both time and money and not a minute of production time was lost!

the flange was welded back on the pump body, and production was resumed *without interruption* the next morning.

Welders like Nickel-Arc because it welds fast and smooth, with a sound deposit that is easily cleaned of slag. Top-notch welders depend on Nickel-Arc, as they do on the other types of electrodes made by the Alloy Rods Company, to do a welding job *right* the first time.

WELDERS: *Send in your experiences with photos! We'd like to use them so that other welders can read about what's going on today. $10 will be paid for each story we use.*

Alloy Rods Co.
York, Pa.

FLAMING-ARC Trademark

Michiana

The November meeting of the Michiana Section was held on Thursday, the 18th, and was favored with a talk on "Flame Hardening" by Frank McGuire, District Engineer for The Linde Air Products Co. Mr. McGuire's first comment was that he wished to squash any ideas that the audience might have that flame hardening is a cure-all for any and all hardening troubles. This production method, like all others, is dependent for its success upon proper selection of steel and of heating and quenching techniques. Many people have the mistaken notion that you can flame-harden any steel, but he stressed that it must be a carbon containing steel, such as SAE 1035 or 4130, or even some of the higher alloys that will harden with an air cool.

Mr. McGuire listed four types of flame hardening: spot, progressive, spinning and combination, where spinning and progressive heating are done simultaneously, quenching usually being accomplished by a spray following the torch.

A number of slides showing machines doing these kinds of heating were shown, as well as a movie of a fully automatic skin type machine. The degree of mechanization of this method of heat treatment is quite astounding.

Dr. Jackson also presented some interesting charts covering the relationship between the size of the weld nugget, cooling rate, hardness and toughness. Most of the discussion pertained to submerged arc welding, but manual welding was also included.

Dr. Jackson, in addition to presenting an interesting technical talk, further entertained his audience with a couple of sleight-of-hand tricks. He showed that he is an expert magician as well as a technical expert by seemingly converting the very solid looking pointer which he had used throughout his lecture into a green turban by a mere wave of his hand.

Instead of a coffee talk, a film of a psychological nature was shown in which the unfortunate chain of events resulting from uninhibited response to daily irritations were presented from a somewhat humorous viewpoint. The intent was to show that a little kindness and thoughtfulness will grease the wheels of social intercourse.

Milwaukee

The November meeting of the Milwaukee Section was held at the Ambassador Hotel on the 19th. Inclement weather reduced the dinner attendance to somewhat lower than average, but a satisfactory group was on hand for the lecture.

The technical talk was presented by Dr. C. E. Jackson, Research Metallurgist of Union Carbide & Carbon Research Laboratories, Inc. Dr. Jackson spoke on "The Effect of Welding Technique on the Metallurgy of Welding," and discussed the relationship between voltage, current, speed of travel and burn-off rate. A number of slides were shown in which the relationship between current and burn off rate for electrodes from $^1/_8$ in. diameter to $^7/_{32}$ in.; the distance between the electrode and plate of the voltage; penetration and voltage and speed of travel and penetration were shown. A final curve based on a mathematical relationship between current, voltage and speed of travel was also presented.

New Jersey

At the December 21st meeting of the New Jersey Section three speakers discussed the inert-gas-shielded metal arc welding process. The speakers were Bernard I. Blickman, head of S. Blickman, Inc., who discussed the phase of welding stainless steel. Newton Blickman cooperated in the preparation of this talk. J. Imperati, Welding Engineer for the American Brass Co., discussed the phase of welding copper base alloys. O. H. Kuhlke, Welding Engineer in Charge of Welding Research for the General American Transportation Co., discussed the phase of welding aluminum.

A motion picture entitled "This Is Steel" was shown prior to these discussions.

The meeting was held in the Essex House, Newark, and was followed by an informal gathering, during which refreshments were served and members discussed their problems with the many experts present.

New Orleans

Delta Tank Manufacturing Co., Baton Rouge, La., one of the sustaining members of the New Orleans Section, put on the October meeting of the New Orleans Section. Seventy-five members and guests were in attendance. Delta Tank Manufacturing Co. fabricates pressure vessels, utilizing both metallic arc and automatic welding in this fabrication. They have just completed a new, large, million-dollar plant to manufacture propane and butane cylinders. Their production line is entirely automatic, and the cylinders are of two-piece construction Unionmelt welded. The Section was given a tour of their entire plant and full explanation of their manufacturing procedure from the drawn halves to the finished tanks. This plant visitation not only proved most interesting but was extremely educational. A stag dinner meeting was then held in town; and J. B. Best, General Superintendent of the Delta Tank Manufacturing Co., highlighted the evening by a detailed discussion of the operations within the plant and production figures on the plant's output.

New York

Harry S. Swan, Welding Engineer for American Locomotive Co., Schenectady, N. Y., addressed the November 10th meeting of the New York Section. His topic was "Welding the Modern Diesel Locomotive." As welding engineer for the Locomotive Division, Mr. Swan has played an important part in the development of the Diesel locomotive, first for switching service and later on for road service. Prior to working on the welded diesel locomotive, Mr. Swan had helped develop the welded steam locomotive boiler.

Mr. Swan's talk consisted of slides on which he made a running comment. At his suggestion, members of the audience broke in with questions during the showing of the slides. This practice made an informal and highly informative session.

Mr. Swan described the production methods used at the various plants of his company. He showed how the manufacture of Diesel locomotives has been made a production-line operation. He explained how the welding method for each operation was selected on the basis of cost and efficiency. He stressed that the design of each welded joint took into account the stresses to which the joints would be subjected in service, the possible difficulty of making a satisfactory weld and the skill of the operators. Members who attended the meeting got a new insight into the manufacture of a piece of heavy equipment that is growing in use.

Arrangements for the meeting were in charge of J. L. Cahill of the New York Navy Yard, Brooklyn, Program Committee Chairman for the Section. The Technical Chairman for the meeting was Norman Schreiner, Manager, Unionmelt Div., The Linde Air Products Co.

The following is the program of meetings for the remainder of the season.

January 20th—Joint Meeting with the Society of Automotive Engineers at the Hotel Pennsylvania, "Welding Problems Encountered in the Automotive Industry." John Randall, Welding Engineer, Ford Motor Co., Dearborn, Mich.

February 25th—Joint Meeting with the Society of Naval Architects and Marine Engineers at the Columbia University Club, "Welding in Shipbuilding." J. Lyell Wilson, Research Director, American Bureau of Shipping, New York, N. Y.

March 16th—Joint Meeting with the American Society of Civil Engineers, "Welded Bridges and Structures." LaMotte Grover, Air Reduction Sales Co., New York, N. Y.

April 13th—The Battle of the Sections—This will be the battle of the century. New York, New Jersey and other nearby Sections of the A.W.S. will participate in a real old fashioned quiz. Which section has a monopoly on welding knowledge? Representatives of these sections will compete against each other for valuable prizes to determine which comes up with the most correct answers to questions submitted by the members.

May—Annual Social Meeting. Date to be announced.

Meetings will be held at the Engineering Societies Building, except where otherwise noted.

Northern New York

"Trends in Resistance Welding Here and Abroad" was the subject presented by Dr. P. R. Hensel of P. R. Mallory & Co., Indianapolis, at the November 18th meeting.

Northwest

November meeting of the Northwest

Section was held on the 9th in the Lodge Room of the Covered Wagon, Minneapolis. Subject: Oxyare Cutting. Speaker: James E. Norcross, Sales Manager of Arcos Corp. A Happy Half Hour at 6:00 p.m. was co-sponsored by Machinery and Welder Corp. and Arcos Corp. Dinner followed at 6:30. Mr. Norcross is thoroughly familiar with the oxyare cutting process and its development. His talk was both interesting and instructive.

Northwestern Pennsylvania

The November 22nd meeting was a combination of a plant visit, social hour, dinner and technical session. The plant visit was made to the Interlake Iron Corp., Erie, Pa., to see their extensive blast furnace and coke oven installation.

Social hour at the General Electric Community Center was held from 6:00 to 6:30 p.m. Bob Huston of Air Reduction Sales was the host.

Another of Mrs. Moss' excellent dinners was enjoyed at 6:30.

Technical session started at 8:00 p.m. with F. A. Bodenheim, Jr., Sales Engineering Manager, Federal Machine and Welder Co., Warren, Pa., as speaker. Mr. Bodenheim spoke on the topic of Resistance Welding on which he is well qualified to speak.

Pascagoula

Wm. Lowe introduced the speaker, J. Lyell Wilson of the American Bureau of Shipping, New York, at the November 3rd meeting held at the Pascagoula Country Club. Mr. Wilson presented a clear cut paper of general interest on the subject "Welding Inspection and Quality Control." New facts and developments were brought out in Mr. Wilson's talk, which was illustrated with slides.

A special feature preceding the technical session was a talk by Mr. Goldman, Chairman of the Gulf Coast Section of the Society of Naval Architects and Marine Engineers. He spoke on organization of Society Section and plans for year's activities.

The December monthly dinner meeting was held on Wednesday, the 3rd, at the Pascagoula Country Club. This meeting was well attended by men from local industries and Mobile, Ala.

The meeting was called to order by vice-chairman John Howkins, who read a message from the chairman R. H. Machy, who was attending a joint meeting of section chairmen in Birmingham, Ala.

Technical speaker for the evening was Professor Jeremiah T. Morrill, Certified Safety Chemist and Engineer of Houston, Tex., Slidell and New Orleans, La. Professor Morrill is the author of a book, "Certified Chemist, the Ship and the Shipyard." This book has recently had the copyright released for publication by the Navy Department for its personnel.

Professor Morrill spoke on the history of gas elimination, economy of complete gas elimination, hazards of welding and burning on tanks, oxygen sufficiency, products of combustion and their source of elimination, new tanks and tanks having been in service. After this brief address, the meeting was turned into a round-table discussion with a large number of those present giving their views and questions to the professor.

Philadelphia

November meeting was held on Monday, the 15th, at the Engineers' Club. F. L. Brandt, Asst. Mgr., Thomson Electric Welder Co., spoke on the subject, "Low Frequency Converter and the Synchromatic Flash Welder."

A panel discussion meeting was held on Friday, December 3rd, in the Junior Room, Engineers' Club. Chairman was K. W. Ostrom of K. Wm. Ostrom & Co. Speaker was W. G. Fetter, Manager, Resistance Welding Division, P. R. Mallory & Co., Inc., who spoke on "New Developments in Resistance Welding Electrodes and Alloys." An extra feature at 7:45 p.m. was the showing of a sound color film "High-Speed Seam Welding of Steel Barrels" through the courtesy of the National Electric Welding Machines Co.

Scheduled of regular monthly meetings to be held at Engineers' Club at 8:00 p.m. for the remainder of the season is as follows:

January 17th—R. M. Ney, Mgr., Industrial Relations, Baldwin Locomotive Works, "Labor Relations and Wage Rates in the Welding Industry."

February 21st—Naval Architects Meeting, R. W. Tuthill, G. E. Co., Engr. Dept., Holyoke, Mass., "Inert-arc Welding as Applied to Shipbuilding."

March 21st—Walter Mehl, Welding Engineer, Heintz Mfg. Co., "How to Select the Best Welding Process for the Job."

April 18th—Harold Baldwin, Engineer, R. G. LeTourneau, Inc., "Welding Procedures in Design."

May 16th—C. B. Voldrich, Research Engr., Battelle Memorial Institute "Weldability of Steels."

Meeting Dates for Special Activities Discussion Groups—February 4th, March 4th, April 1st and May 6th.

Pittsburgh

Regular monthly meeting was held on Wednesday, November 24th, in the Auditorium of the Mellon Institute of Industrial Research. George J. Green and Donald H. Marlin, Engineering Works Division, Dravo Corp., Pittsburgh, were the speakers. Their subject was "Automatic Welding as Applied to Structural Fabrication." The speakers discussed the start (during the war) in submerged arc welding, the amount of equipment secured, early tests and experiments endeavoring to find sufficient work for the equipment, the final accepted work and their present-day work which involves a variety of odd uses of submerged arc rather than the ordinary setting-up of operations on repetitive work.

Preceding the above, H. E. Cable, District Manager, Lincoln Electric Co., arranged for the showing of their new film, "Designing Machinery for Arc Welding." This is a sound, color film and ties in very closely with the subject discussed.

Portland

A one and one-half hour tour was made of the Reynolds Metals plant at Troutdale, Ore., on November 23rd. The tour was conducted by W. A. Noels, C. Langlois, V. Kneeskern and Harry Wright of the Reynolds Co.

Many of the members were greatly surprised at the extensive process bauxite experiences before becoming aluminum.

After the tour, coffee and doughnuts were served at the cafeteria.

Refreshments were followed by the showing of a colored picture entitled "Pigs in Progress" which illustrated mining, smelting and fabrication of the metal into finished products.

Mr. Bristow, Program Chairman of the Portland Section, thanks the members of the Reynolds Co. for their time and effort put forth in behalf of the Section.

Rochester

The November meeting of the Rochester Section was held at the University of Rochester on November 15th.

R. J. Metzler of Handy & Harman, presented an interesting talk on "Design for Silver Brazing." He amplified his talk with slides and sound movies.

Also on the program was a movie entitled, "Jet Propulsion," shown through the courtesy of the General Electric Co.

Nine new members were welcomed by Fred Hall, Chairman of the Section. Mr. Hall also reminded the members of the Educational Program, starting January 10th. All persons interested in welding or design for welding are invited to attend this series of six lectures. The presentation will be under the direction of William J. Conley.

San Francisco

James A. Kavenaugh, Technical Advisory Service, Revere Copper and Brass Inc., Los Angeles, presented a highly technical address on "Welding of Copper and Its Alloys" at the November 22nd meeting held in the Engineers' Club. A film, "Copper and Its Alloys," was shown in conjunction with the talk.

W. H. Popert presented a report on the progress of the Structural Committee.

Syracuse

Dinner at the Hiawatha Room, Hotel Onondaga, preceded the technical session of the December 8th meeting. Coffee Speaker was Attorney Bernard J. Donoghue who spoke on the Taft-Hartley Law. Technical Chairman was Mr. Harrington. Subject of the technical meeting was "Resistance Welding and the Future Responsibilities of the A.W.S." and was presented by George N. Sieger, President of the S.M.S. Corp. and President of the A.W.S. Mr. Sieger discussed the advances made in this field and gave many humorous comments, which all added up to one of the best meetings of the year.

Toledo

A 4-man panel discussed inert arc

welding at a recent meeting of the Toledo Section held at the Commodore Perry Hotel. Sam W. Snell was program chairman.

Tri-State

September dinner meeting was held on the 30th at the Vendome Hotel, Evansville, Ind. Mr. Chovinard presented a highly technical talk on "Oxyacetylene Cutting Machines."

October dinner meeting was held on the 28th in the Vendome Hotel, Evansville, Ind. Paul Feld presented an interesting talk on "Fundamentals of Silver Brazing." A film was also shown on this subject.

November dinner meeting was held on the 19th in the Vendome Hotel, Evansville. E. A. Mallett of Taylor Winfield gave a clear cut, interesting talk on Everyday Problems of Resistance Welding.

Washington

Dinner at O'Donnell's Restaurant preceded the regular monthly meeting held on November 30th in the Pepco Auditorium. Van Rensselaer P. Saxe presented a highly interesting talk on "Some Welded Building Structures," at the technical meeting.

Western Massachusetts

November 23rd meeting was held at the Sheraton Hotel, Springfield, Mass. R. W. Tuthill, General Electric Co., Holyoke, Mass., presented two interesting subjects: "Arc Welding at Work" and "Inside of Resistance Welding."

Following the technical session a sports film on the Zale-Graziano Fight was shown.

Western Michigan

The first dinner meeting of the 1948–49 season of the Western Michigan Section was held on Monday evening, September 27th, at seven o'clock at Crackels Highway Grill, Grandville, Mich.

A very fine dinner was served to approximately 95 members and guests, at which time the new officers and members of the Executive Committee for the fiscal year commencing September 1948 were introduced. After the introductions were over, a short business meeting was held.

The speaker for the evening was D. C. Smith, Chief Metallurgist, Electrode Division, Harnischfeger Corp. His subject, "Electrode Coatings and Their Influence on the Properties of Arc-Welding Electrodes," was a highly interesting subject. A very thorough and lively discussion followed, which dealt principally with the effects of low-hydrogen electrode welding, with everyone participating, which concluded a very successful evening.

The second dinner meeting was held on Monday evening, October 18th, at Crackels Highway Grill, Grandville. This meeting was set ahead one week so as not to conflict with the Annual Meeting in Philadelphia. Quite a number of the members of this Section attended the Annual Meeting.

There were 120 members and guests present to hear Arthur William from Federal Machine and Welder Co. speak and show slides and moving pictures on resistance welding. Questions and discussions were encouraged during the meeting.

Refreshments were contributed by three companies from Grand Rapids: Purity Cylinder Gas, Welding Gas & Supply Co., Inc., and Aladdin Rod & Flux Co., which were greatly appreciated and enjoyed by all.

Western New York

A joint meeting with the Buffalo Section, Society of Automotive Engineers was held at the Buffalo Trap & Field Club, Cheektowago, N. Y., on November 12th. Eighty members and guests were present for the turkey dinner and social hour which preceded the technical session. Ed Hebeler, Hebeler Welding Co., who has long been associated with activities in the local section, demonstrated a quick-connecting device for arc-welding electrode holders and cable connections which he had developed in his spare time. The simplicity and versatility of the device amazed all who saw it.

Approximately 100 additional members and guests were on hand to welcome John D. Gordon, Vice-President and General Manager, Progressive Welder Co., who presented the main topic of the evening. His informative and complete presentation on "Design for Welding" was well received by all. Mr. Gordon emphasized the importance of proper design when using resistance welding processes and was ably assisted by Mr. Stanley in presenting solutions to many problems which have been encountered in the automotive industry, wherein improved design has greatly increased efficiency in production. Many who attended were gratified to learn of the new booklet which is to be published by his company. This booklet will enable management as well as the design and production engineering sections of any organization to understand more fully the efficient use of the equipment available.

Worcester

John Lang, Welding Engineer and Assistant Superintendent of Lukenweld Division, Lukens Steel Co., Coatesville, Pa., spoke before members of the Worcester (Mass.) Section at their meeting on Monday evening, November 29th, at the Sheraton Hotel.

Mr. Lang discussed the general subject, "The Manufacture of Welded Machinery," illustrating his talk with examples of papermaking, earthmoving, power generating and other industrial equipment which Lukenweld has fabricated.

Canadian

The second meeting of the 1948–49 season of the Montreal Chapter of the Canadian Welding Society was held on Monday, November 15th, in the Queen's Hotel, Spanish Room. "Welding Applications in a Structural Plant" was the subject presented by Gordon Cape, Division Welding Engineer, Methods and Research Dept., Dominion Bridge Co.

The third meeting of the 1948–49 series of the Kitchener-Waterloo Chapter was held on Wednesday, December 1st at Massey Hall, Ontario Agricultural College. "Welding Metallurgy" was the subject presented by Dr. G. E. Willey, Chief Metallurgist, Algoma Steel Corp. Ltd., Sault Ste. Marie, Ont.

Monday, December 6th, was the meeting day for the Toronto Chapter at Malloneys Art Gallery. John D. Tebben, Vice-President, S.M.S. Corp., Detroit, Mich., spoke on "Some Factors to Be Considered in the Selection of Resistance Welding Electrode Material."

Meeting dates for the Toronto Chapter for the remainder of the season are:

February 7th—"Field Welding of Pressure Vessels," Lyle Meredith, Chief Construction Engr., M. W. Kellogg Co.

March 7th—Film Night.

April 4th—"Welding Construction in Canada," D. Boyd, J. Inglis Co., Toronto.

May 2nd—"Stump the Expert's Night."

The third meeting of the 1948–49 series of the Hamilton Chapter was held on Tuesday, December 7th, at McMaster University. John D. Tebben, Vice-President, S.M.S. Corp., Detroit, Mich., spoke on "Some Factors to Be Considered in the Selection of Resistance Welding Electrode Material."

The third meeting of the 1948–49 season of the Ningara District Chapter was held on Wednesday, December 8th, at St. Catharines Collegiate. W. A. Duncan, Sales Manager, Dominion Oxygen Co. Ltd., Toronto, Ont., spoke on "A Quarter of a Century of Progress in Welding."

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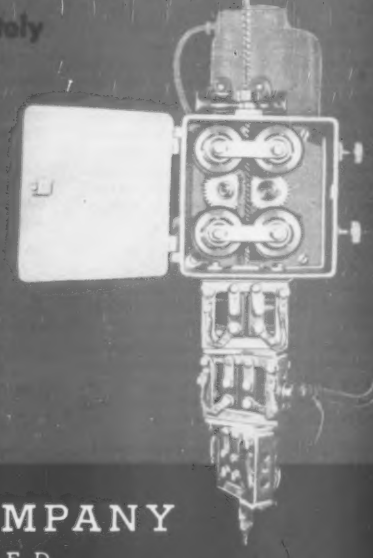

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abstracts of
CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 10, D. C.

2,452,060—Ignition Indicating Device for Welding Systems—Hans Klemperer, Belmont, Mass., assignor to Raytheon Mfg. Co., Newton, Mass., a corporation of Delaware.

This welding system includes a resistance welding load device having a circuit for supplying welding current impulses to the load device. A controlled ignition discharge tube is in the circuit as are means for igniting the tube to supply impulses to the load device. An inductance is also present and has a rectified discharge tube in circuit in shunt therewith, which tube conducts current upon reversal of the voltage across the inductance. Signal generating means are connected individually to each of the tube circuits.

2,452,070—Resistance Welding Forging Pressure Control—Lloyd Daniel Runkle, Gloucester, Mass., assignor to Raytheon Mfg. Co., Newton, Mass., a corporation of Delaware.

The patented control system relates to a control for the forging pressure applied to the work in resistance spot welding. The control includes means responsive to the flow of a welding impulse to the work for controlling a high voltage current impulse to a solenoid which controls a pressure control device. A low voltage holding circuit is connected to the solenoid after the high voltage current impulse and other means return the pressure control device to its normal position after a time interval in which the solenoid is de-energized.

2,452,199—Welding Electrode Holder—John L. King, Detroit, Mich., assignor to Miracle Lubricating Co., Detroit, Mich., a corporation of Michigan.

King's electrode holder has a pair of members mounting electrode holding jaws at their forward ends. Two cams are associated with the members for controlling their positions.

2,452,303—Multiple Welding Pressure Roll Assembly for Electric Weld Tube Mills—Carl J. Honen, Youngstown, Ohio, assignor to The McKay Machine Co., Youngstown, Ohio, a corporation of Ohio.

This patent covers a continuous butt-weld tube mill wherein a plurality of rolls are provided for applying compressive pressure to the tube on opposite sides of a welded cleft therein.

2,452,573—Direct-Current Apparatus for Welding Utilizing Energy Storage Apparatus—Fred H. Johnson, Pleasant Ridge, and Chester F. Leathers, Detroit, Mich., said Leathers assignor to Progressive Welder Co., Detroit, Mich., a corporation of Michigan.

Johnson's direct current welder includes electrode conductors which are free of electrical inductance except for the inherent self-inductance thereof. Substantially noninductive circuit controlling means control flow of current through the circuit and have three operative conditions for varying the flow of welding current through the circuit. Predetermined time intervals can be set up to regulate the position of the controlling means with all of the inductive stored energy in the circuit being dissipated prior to the interruption of any current flow in the circuit.

2,452,574—Method of Welding Seam Portions of Electrically Conducting Articles—Lyman L. Jones, Seattle, Wash., assignor to American Can Co., New York, N. Y., a corporation of New Jersey.

This patent relates to the welding of seam portions of electrically conducting articles and has the seam portions of the articles positioned in opposed relation. An electric welding current passes from the seam portions of one of the articles directly to the seam portions of the other, to weld such seam portions and produce two separate and independently welded articles.

2,452,718—Cutting Torch Holder—James Henry Blythe, Denver, Colo.

In this patent a special guiding attachment for a cutting torch holder is disclosed.

2,452,805—Composition of Matter for Sealing Spot-Welded Joints—Paul Sussenbach, St. Louis, Mo., assignor to The Presstite Engineering Co., St. Louis, Mo., a corporation of Missouri.

The composition covered in this patent comprises cellulose nitrate, a fugitive solvent mixture, a major portion of castor oil and a small portion of carbon black, having aluminum flakes dispersed therethrough.

2,452,876—Welding Rod and Electrode Holder—Henry Shaw, Bessacarr, Doncaster, England.

Shaw's electrode holder has a tubular body with a weld rod receiving head having a guide-way therein. Separately renewable insulating cover members are provided for the rod receiving head.

2,452,995—Soldering, Brazing and Welding Fluxes—Lionel Cinamon, New York, N. Y.

This special flux includes boric acid and an alkali fluorine compound. The flux also has an acid of pentavalent phosphorus and an alkali metal salt thereof in it to impart a limited range of phosphorus content to the flux.

2,453,244—Electrode Grip and Holder—Ivan M. Matson, Los Angeles, Calif.

The electrode holder disclosed by this patent has a channel-shaped jaw and an inverted channel-shaped jaw associated with a handle member.

2,453,320—Welding Electrode Holder—Ernest W. Huebner, Detroit, Mich., assignor to Weiger Weed & Co., Detroit, Mich.

Huebner's holder is tubular and has a socket at one end for frictionally retaining an electrode tip. A fluid transmitting circuit is formed in the holder and special tubes are received therein for forming the desired fluid circuit.

2,453,407—Welding Line Reel Switch—Jake D. Burns, Richmond, Calif.

A self-winding reel for electrode cables is covered by this patent.

2,453,438—Electric Welding Apparatus—William S. Horth, Cleveland Heights, Ohio.

Horth's patent relates to a conversion unit for changing a spot-welding machine into a seam-welding machine and includes bearing blocks that are detachably connected to the upper and lower spot-welding arms of a conventional machine. A shaft is journaled in each of the blocks and has a welding wheel secured thereto while flexible drive means are secured to and extend between the shafts. Drive means are provided for the shafts.

2,453,576—Spot Weld Tester—Fraser B. Jacob, Lynn, Mass., Assignor to The Electroloy Co., Inc., Bridgeport, Conn., a corporation of Connecticut.

This spot-weld tester relates to a measuring head for a spot-weld coupon testing device and has resilient restraining means for transmitting movement from a gripping head to the restraining means. Another element indicates the deflection of a

restraining means while another device retains a reading of the indicating means.

2,453,648—Electrode Holder—Henry J. Wagner, Jackson, Mo.

Wagner's holder includes a main jaw and a secondary jaw that are secured on a tubular handle with an operating element being provided for moving the secondary jaw assembly with relation to the main jaw assembly.

2,453,768—Welding Electrode Holder—Wayne Tinnell, Cincinnati, Ohio.

The electrode holder of this patent has a metallic tubular cage with a transversely bored clamp shaft associated therewith and having an insulating material cover secured to a projecting end of such shaft.

2,453,950—Hendrin Jan van den Berge and Hendrik Peter Hubee, Eindhoven, Netherlands, assignors to Hartford National Bank & Trust Co., Hartford, Conn., as trustee.

The device of this patent is for touch welding and includes two holders for welding rods which are positioned thereby in parallel relationship. A common mounting is provided for the two holders and permits longitudinal movement of the holders whereby the mounting device can be moved to bring either of the two holders in a given position with regards to a work piece.

2,454,190—Resistance Welding Apparatus and Jig Therefor—Winfred N. Lurcott, Elizabeth, N. J., assignor to L. J. Wing Mfg. Co., New York, N. Y., a corporation of New York.

The apparatus of this patent includes an electrode which is movable toward a first object to which a second object carried by the electrode is to be welded. Special jaw means secure the objects to be welded together to the electrodes.

LIST OF NEW MEMBERS

November 1 to November 30, 1948

ANTHONY WAYNE

Altekruse, Kenneth Albert (B)
Anspach, Clarence (B)
Cary, Carl G. (C)
Davis, Don F. (B)
Hoffman, William F. (B)
Lang, Frank (B)
Nesser, Donald F. (B)
Spicer, Karl J. (B)

BOSTON

Wells, Clarence M. (C)

BRIDGEPORT

Ott, George E. (C)

CHICAGO

Butler, Thomas S. (C)
De Wold, Lee H. (B)
Mitchell, Peter M. (B)
Woollard, Donald E. (C)

CINCINNATI

Finnell, Harry E., Jr. (B)
Kreider, Lloyd E. (B)
Miller, J. Brewster (C)
Noll, Edward M. (C)

CLEVELAND

Hoenie, Norman J. (C)
Wolfenden, J. T., Jr. (C)

COLORADO

Hynds, James H. (B)
Tajire, Tancharee (C)

COLUMBUS

Anderson, Walter A., Jr. (D)
Bellware, Morris D. (D)
Green, William Lee (D)
Harvey, William D. (D)
Keyte, Jack B. (D)
Weber, Gervase George (D)
Zimpfer, Roger A. (D)

DAYTON

Allison, C. R., Jr. (C)

DETROIT

Adams, Wm. C. (B)
Ansteth, Robert M. (D)
Belanger, Thomas D. (D)
Blackmore, Thomas W. (D)
Brick, Arthur E. (D)
Eichner, Ferdinand R. (C)
Ewing, Thomas A. (D)
Gorno, Anthony S. (B)
Halling, Paul (B)
Heidtman, Herman F. (C)
Huber, William F. (B)
Klain, Paul (C)
Makulinski, Irving S. (D)
Muscarella, Lawrence J. (D)
Narayan, K. V. (D)
Oxenrider, Carman J. (D)
Piette, Philip J. O. (D)
Polk, William J. (D)
Rodehorst, Robert L. (D)
Schroeder, Harold I. (C)
Smith, Howard A. (D)
Spitzley, Joseph H. (C)
Spitzley, Roy Lester (B)
Thompson, Garth S. (B)

HARTFORD

Marklund, Carlo (C)
Sayles, Robert W. (B)
Treat, Robert M. (C)

INDIANA

Angrick, Herman F. (B)
Lindley, Roy W. (B)
Watts, Fred (B)

INLAND EMPIRE

Axelson, Ralph (C)
Butcher, Gerald Austin (C)
Downey, C. S. (B)
Hartman, D. S. (B)
Hetzler, Charles C. (C)
Mc Crea, W. K. (B)
Sevits, Winford D. (C)

KANSAS CITY

Arndt, Donald A. (C)
Bryant, Roy William (C)
Clune, Peter F. (C)
Gibbons, Wilburn L. (C)
Lasley, Ray H. (C)
Tally, Glenn D. (C)
Tomlin, Larry (C)
Watkins, Edgar H. (C)
Watts, Bert B. (C)
Wood, Lloyd Nelson (C)
York, Darryl T. (C)

LEHIGH VALLEY

Price, Wayne D. (C)

LONG BEACH

Lewis, Thomas R. (B)

LOS ANGELES

Curtis, Elbert D. (B)
Toland, John A. (C)
Wiley, John B. (C)

LOUISVILLE

Bruno, Charles (C)
Case, Jay (B)
Fitzgerald, Carl (B)
Henby, John A. (B)
Hottman, June (B)
McCutchan, Arthur (B)
Sands, Lawrence (B)
Williams, John O. (B)
Yarbro, Roba (C)

MARYLAND

Bruff, Charles M. (C)
Lees, Aldridge Le Roy (C)

NASHVILLE

Boyd, Doyle Arthur (B)
Lynn, J. A. (C)

NEW JERSEY

Abeles, James D. (B)
Bazaz, Henry (B)
Castellani, Louis (C)
Flynn, Paul H. (C)
Holloway, Abner P. (C)
Perkins, Albert F. (C)
Schutz, Henry (B)
Stout, Joseph D. (C)
Walter, Paul R. (B)

NEW ORLEANS

Karney, Charles H. (C)

NEW YORK

Bankes, Ralph A. (B)
Brown, David P. (B)
Guinan, John F. (B)
Gulliver, Arthur W. (B)
Johansen, Haylett (C)
Litzenberger, Wilson S. (C)
Maciejewski, Felix J. (C)
Maddox, Robert C. (B)
Murphy, Frederick A. (C)
Reaber, Henry W. (C)
Redman, Joseph (B)
Stewart, Edwin Lawson (B)
Wirtz, Adolph H. (C)

NORTHWEST

Morton, O. W., Jr. (C)

OKLAHOMA CITY

Barnes, Ralph (D)
Oeltjendiers, Lee Roy (D)

PORTLAND

Johnson, Kerby E. (B)

ROCHESTER

Ellicott, Albert (C)
Schmitt, Charles W. (C)

ST. LOUIS

Bruenger, Edwin H. (D)
Jablonsky, R. D. (C)
Vaughan, James H. (C)

SAN FRANCISCO

Butler, Ellis F. (B)

SOUTH TEXAS

Alexander, June L. (B)
Bailey, L. C. (B)
Bruckmiller, Edwin (C)
Files, Sidney J., Jr. (C)
Key, Howard E. (B)
O'Neill, John H., Jr. (C)
Pape, H. (B)
Phillips, D. B. (B)

SYRACUSE
Olski, David F. (C)
Virkler, Verne (C)

TULSA
Looney, R. L. (B)
Zilm, Frederick W. (C)

WASHINGTON
Absher, Richard R. (B)
Evert, Richard H. (B)

WESTERN MICHIGAN
Mohlie, J. R. (B)

WORCESTER
Vinson, A. F. (B)

NOT IN SECTIONS
Draper, Henry E. (B)
Mawer, Arthur L. (C)
Pal, C. R. (B)
Scortecci, Prof. Dr. Antonio (B)

Members Reclassified

During the Month of November

ANTHONY WAYNE
Hamilton, Harold (C to B)

BIRMINGHAM
Schauerte, Gerald E. (C to B)

DETROIT
David, William J., Jr. (C to B)

PEORIA
Garver, Frank B. (C to B)

WESTERN NEW YORK
Schilling, Frederick V. (C to B)

(*Continued from page 92*)

remote electrical control and was designed to make square, burrless cuts across heavy steel sections, such as structural shapes. Its teeth whirr faster than 320 miles an hour at its normal speed of 1750 revolutions a minute. When the blade makes contact with hard, tough steel, friction generates more rapidly than the material can absorb it. The intense heat melts the surface and the teeth carry it away. A transparent plastic shield assures perfect safety for the operator as the sparks fly fast. This is the first of several high-speed friction saws to be installed at warehouses of this United States Steel Corp. subsidiary and is considered the most modern in the steel industry.

Hard-Surfacing Powder

An improved hard-surfacing powder, called Surfaceweld A, has been made available by The Lincoln Electric Co. of Cleveland, Ohio. The powder, to be applied with a carbon electrode, is used for depositing a thin chromium carbide type of hard surface that is highly resistant to abrasive wear and corrosion.

The operating characteristics of Surfaceweld A give it a wide field of application. One of its outstanding characteristics is its ability to be used with an a.-c. arc with a single carbon electrode. It may also be applied with a twin carbon arc or may be used with d.-c., carbon electrode negative.

Surfaceweld A is designed for surfacing applications where the use of hard-surfacing electrodes is not always practical:

(*a*) Thin work
(*b*) Thin deposits
(*c*) For use with small a.-c. welders

It is also used in preference to hard-surfacing electrodes for certain conditions of severe abrasion. The powder forms a paste when mixed with water which adheres to flat and curve surfaces.

The hardness of the smooth dense deposit of Surfaceweld A is approximately 54-61 Rockwell C for one layer and 57-63 for multiple layers. Hardness depends somewhat on the amount of admixture. The deposit develops full hardness in the as-deposited condition; maintains hardness and resists scaling at elevated temperatures. Corrosion resistance is comparable to that of stainless steel.

The advantages of the powder form of hard surfacing may put to good use on such jobs as maintaining the cutting edge of mixing blades, drill bits, surfacing augurs, dipper teeth, bucket lips, forming dies, cement block formers, scraper blades, cableway drums; it is also excellent for withstanding the abrasive action of the earth on tools such as hoes, shovels, garden tools; farm implements such as disk plows, plow share points, bean knives and corn cutters.

Surfaceweld A is available packed in convenient one-pound cans.

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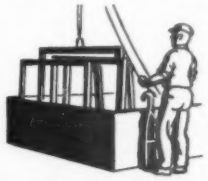

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Supplement to The Welding Journal, January 1949

Notch Sensitivity of Welded Steel Plate

This paper contains additional observations on the properties of various compositions of steel plates as affected by welding conditions and treatments

by R. D. Stout and L. J. McGeady

INTRODUCTION

THIS paper is a report of additional investigations carried out at Lehigh University on the properties of steel plates as affected by welding, mechanical treatment, and heat treatment. It is, therefore, a continuation of work reported previously.[1-3]

The phases considered in the present work included the following:

1. The origin of crack formation as affected by steel composition, welding conditions and postheating.
2. Effect of normalizing temperature on prime plate and on subsequently welded plate.
3. A study of the factors affecting the ductility and fracture transition temperatures.
4. Further consideration of the significance of ductility vs. mode of fracture as criteria of the transitional behavior of structural steels.

R. D. Stout and L. J. McGeady are connected with the Metallurgy Department, Lehigh University, Bethlehem, Pa.

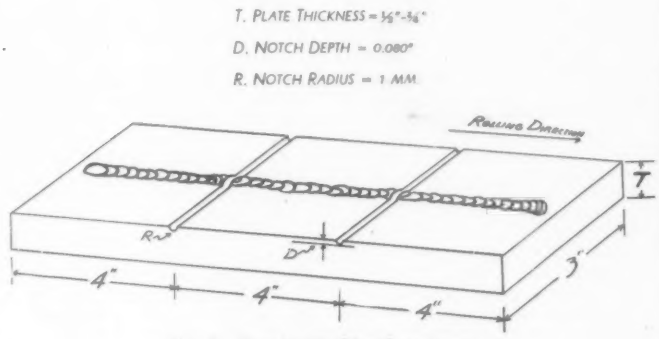

Fig. 1. Longitudinal bend specimen

The specimen shown in Fig. 1, the longitudinal notch-bend test, has been used as the testing method and has been described previously.[1]

Table 1—Effect of Steel and Welding Conditions on Cracking Tendency; Longitudinal Notch Bend Tests with Increment Bend Angles

Test series	*Steel*	*Welding condition**	*Special treatment*	*Angle of first crack, deg.*	*Locus*	*Transition temperature at 1% lateral contraction, ° F.†*
1	KA	Prime plate	.....	10	.....	−60
2	KA	E6010, 175A, 15 in./min.	.....	3	Coarse grains	60
3	KA	E6010, 175A, 6 in./min.	.....	5	Coarse grains	0
4	KA	E6010, 175A, 15 in./min.	Postheat 1200° F.	5	Coarse grains	−50
5	KA	E6010, 175A, 15 in./min.	Notched below coarse grains	3	Intercritical structure	60
6	U	E6010, 175A, 10 in./min.	.....	9	Weld metal	−25
7	BC	E6010, 175A, 10 in./min.	.....	10	Weld metal	−50

* All welds were deposited by an automatic head at 28 v., reverse polarity.
† See text for explanation of "1% lateral contraction" under "Effects of Normalizing."

Table 2—Characteristics of the Steels in the Testing Program

Steel code	Deoxidizing practice	McQuaid-Ehn grain size	C	Mn	Si	P	S	Cr	Ni	Other	Plate thickness, in.
U	Al-killed	8	0.16	0.54	0.20	0.012	0.024	0.02	0.04	0.06 Cu	5/8
H	Rimmed	3	0.25	0.36	..	0.016	0.031	0.04	0.15	0.19 Cu	5/8
BL	Semikilled + Al in mold	5–7	0.15	0.47	0.09	0.014	0.035	..	*	.....	3/4
BH	Semikilled	2–4	0.18	0.50	0.08	0.014	0.027	..	*	.....	3/4
BC	Semikilled	2–4	0.18	0.73	0.06	0.013	0.031	..	*	.....	3/4
BF	Semikilled + Al in mold	5–7	0.18	0.73	0.06	0.013	0.031	..	*	.....	3/4
KA	Si-killed	...	0.25	0.66	0.19	0.020	0.022	0.04	0.07	0.06 Cu	1/2
KB											3/4
KC											1
YC	Semikilled	...	0.25	0.49	0.05	0.015	0.029	0.01	0.01	.....	5/8
WB	Rimmed	...	0.21	0.36	0.01	0.016	0.029	0.09	0.15	.....	3/4
PH	Killed	...	0.23	1.60	0.23	0.017	0.029	0.19	0.21	0.013 Ti	7/8
AA	Killed	...	0.20	1.44	0.33	0.016	0.029	0.20	0.15	0.010 Ti	1
OB	Killed	...	0.19	1.39	0.31	0.023	0.022	0.07	0.10	0.012 Ti	7/8
NB	Killed	...	0.15	1.10	0.23	0.026	0.040	..	..	0.029 Ti	1
DC	Killed	...	0.14	1.29	0.29	0.023	0.020	0.05	0.06	0.014 Ti	1
MC	Killed	...	0.14	1.29	0.18	0.029	0.040	..	..	0.015 Ti	1
LA	Killed	...	0.13	1.24	0.27	0.016	0.019	0.09	0.15	0.009 Ti	1

*ADDITIONAL DATA

Steel code	Nitrogen: Wet method	Nitrogen: Vacuum fusion	Aluminum: Total	Aluminum: Al_2O_3
BC	0.0045	0.0025	0.008	0.002
BF	0.0053	0.0024	0.043	0.005
BL	0.0044	0.0027	0.028	0.004
BH	0.0042	0.0023	0.003	0.002

EXPERIMENTAL RESULTS

Origin of Cracking

In an earlier report[2] it was shown that the first crack formed during the bending of a welded longitudinal bend test initiated in the grain boundary material of the coarse grains in the weld heated zone. The initial crack became visible in cross sections examined under the microscope after low angles of bending. For example, a crack was found in a welded 3/4-in. 0.25% C steel plate (Steel KB in Table 2) which had been bent only 1 1/2°, although in duplicate specimens failure as indicated by a dropping of the load did not occur until 7° of bending. It was decided to investigate whether any relation existed between the angle at which cracking started and the transition temperature for several steels, welding conditions and postheat.

The technique used to detect cracking was the same as that developed previously. A series of duplicate specimens were given increments of bending from 1° to failure. Each notch area was then sectioned and polished on a plane parallel to the plate surface and at a depth just barely below the root of the notch. The lowest angle of bend at which a crack could be observed in the polished area was then taken as the angle of initial cracking. In all cases the temperature at which bending was carried out was chosen so that cleavage failure would have resulted if the bending had been carried to completion. Two series of specimens, prime KA plate, and welded KA plate, were also bent at a temperature known to produce shear failure. No change in the angle at which the first crack formed was observed at this higher temperature.

In Table 1 are listed the steels tested, welding condition, if any, and any other special treatments, together with the angle of first cracking and the ductility transition temperature. Welding is found to encourage cracking in KA steel, as it is to be expected. (Compare Test 1 with tests 2 and 3.) Higher heat input or postheating reduces the cracking tendency (Test 2 vs. test 3 or 4). If the notch is cut deeper so as to cut through and eliminate the coarse grains of the heated zone, the crack still forms at 3°, as in Test 5. This agrees with previous tests in which it was shown that weld zone structures, formed by heating within the critical range, were just as brittle as the coarse, overheated grains. If lower carbon plates are welded and tested, as in tests 6 and 7, the crack is found to form in the weld metal instead of the parent metal. Apparently here the weld metal is the least ductile material present.

In all of these tests a rough correlation between the angle of first cracking and the ductility transition temperature can be noted.

Effects of Normalizing

One of the objectives of this investigation has been to find ways of improving the response of structural steels to welding. While more elaborate heat treatments, such as quenching and tempering prior to

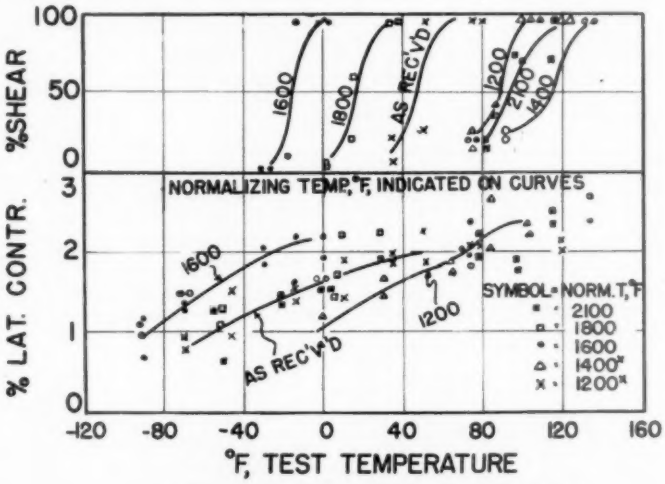

Fig. 2. Effect of normalizing 25% C, 1/2-in. plate

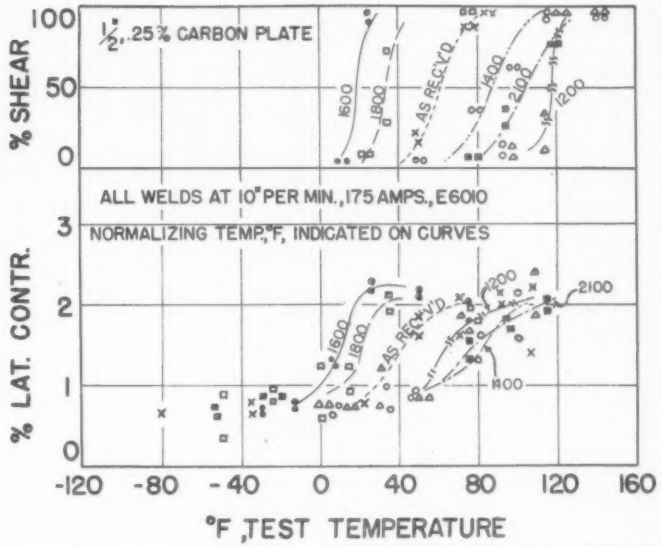

Fig. 3. Effect of normalizing before welding (Air cooling from 1200 and 1400° F. does not constitute normalizing)

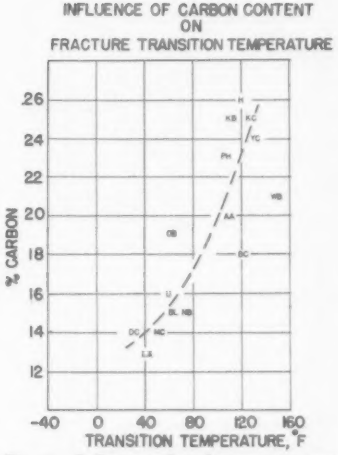

Fig. 4. Influence of carbon content on fracture transition temperature

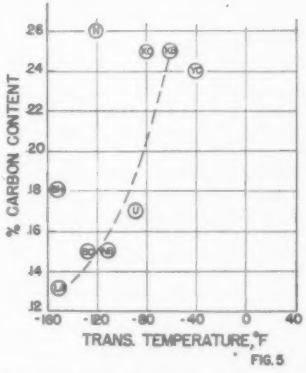

FIG. 5

Fig. 5. Effect of carbon on ductility transition temperature of unwelded plate

welding, were shown to be effective,[2] normalizing is the most practicable source of improvement.

It was decided that the optimum temperature of normalizing should be determined for prime plate and for subsequently welded plate on the basis of ductility transition temperature and also on the basis of fracture transition temperature, since it was by no means certain that they would agree on this point. KA steel was normalized in specimen size at a series of temperatures and then tested without welding and with welding. In Figs. 2 and 3 the behavior of the steel in these tests is shown. The mode of fracture is given in terms of the percentage of shear failure observed on the fractured cross sections. The ductility was measured by observing the width of the specimen at a point $^1/_{32}$ in. below the notch, before and after testing, according to the method of Kinzel.[4] The inward movement of the notch extremities is called lateral contraction and is expressed in per cent.

The fracture transition temperature is defined here as the temperature at which the fracture is 50% shear type. The ductility transition temperature is defined as the temperature at which the lateral contraction is 1%.

In Fig. 2 the unwelded plate is shown to respond strongly to normalizing. The fracture transition temperatures are spread over a range of 120° F. Normalizing at 1600°F is decidedly the best treatment. The detrimental effects of excessively high or low temperatures are evident from the 2100 and the 1400° F. curves. The low values obtained after heating to 1200° F. are not easily explained, unless an aging effect is responsible. The ductility values are also noticeably affected by normalizing, but there is more scatter present among the points. Here again, however, 1600° F. appears as the best normalizing temperature.

In Fig. 3 the influence of normalizing prior to welding is shown. The fracture transition curves appear at virtually the same positions in the graph as they did for the unwelded plate of Fig. 2. This is in keeping with the fact that welding does not appear to alter the fracture transition temperature markedly.[3] The ductility transition curves in Fig. 3 show a strong tendency to coincide in temperature with the fracture transitions. This fact will be discussed further in a later section.

These tests show that normalizing can have a potent effect on the transition temperature of the steel, whether welding follows or not. The use of normalizing from the proper temperature to improve notch sensitivity is therefore a very practical way to increase the weldability of a steel. It is possible that similar benefits might be obtained, at least in lighter gages, by controlling finishing temperatures on the mill.

Relative Behavior of Ductility and Fracture Transition Temperatures

It was previously noted that the operation of welding raises the ductility transition temperature considerably but has little influence on the fracture transition temperature. It may be of some value to assemble the data which have been obtained on the slow-notch bend test to show the effects of certain variables on these two transition criteria. Included among these variables are the following: (1) carbon content, (2) deoxidation practice, (3) plate thickness, (4) normalizing, (5) welding and postheating and (6) straining and aging.

Carbon Content

Examination of a large number of heats of steel has revealed that of all the alloying elements carbon is by far the most influential on transition temperature. In Fig. 4 the fracture transition temperature is plotted versus carbon content and in Fig. 5 the ductility transition temperature versus carbon content, as determined in as-rolled plates. These points, the letters of which refer to the steel codes in Table 2, represent a mixture of rimmed, semikilled and killed heats and also carbon and alloy heats. Both ductility and fracture transitions follow carbon content, although the

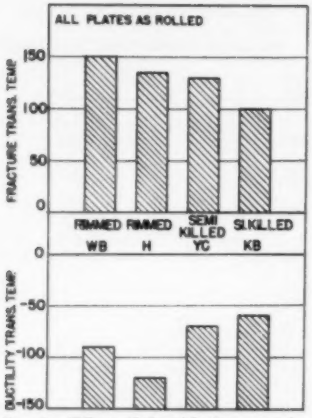

Fig. 6. Effect of deoxidation practice on transition temperatures

ductility transition is more subject to scatter.

Deoxidation

Two rimmed heats (WB and H), one semikilled (YC), and a silicon-killed heat (KB)—all of about 0.25% C—were available for comparison. The fracture transition temperatures and ductility transition temperatures for these steels are given in Fig. 6. The fracture transitions are definitely better in the killed steel. The ductility transitions do not show this trend.

The influence of the rim and core of a rimmed heat on its ductility behavior was given additional study. H steel rolled to $^5/_8$ in. was planed on one side to $^1/_2$-in. thickness. In addition to unwelded specimens, samples were prepared with weld beads placed on the untouched rim side in one series of plates, and on the exposed core side in a second series. In Fig. 7 the notch-bend test ductility values are shown for both series. The core is lower in ductility and higher in ductility transition temperature than the rim in both unwelded and welded tests. The fracture transition temperatures, however, were identical, 135° F. Thus, the ductility of a rimmed steel tested in bending is likely to be quite good, while at the same time, its fracture characteristics will likely be relatively poor.

Plate Thickness

Several steels were available in more than one rolled plate thickness. Steels U and K (KA, KB, KC) were tested in multiple thicknesses. In Fig. 8 are shown the fracture characteristics of the different thicknesses, and in Fig. 9, the ductility transition temperatures.

The fracture transition temperature is raised with increasing plate thicknesses. The ductility transition is not consistently affected by increasing thickness. It is known that thickness can operate in two ways to produce its effect on the fracture. First, the amount of reduction, finishing temperature and cooling rate introduce metallurgical differences among the various thicknesses. Second, the geometry of the test specimen, and, with it, the constraint, alter the conditions of testing. Of the two, the metallurgical effect is usually more pronounced. In order to show this, KC was machined to $^1/_2$- and $^3/_4$-in. thickness before testing. Results are presented in Figs. 10 and 11. The fracture transition varied only slightly with thickness, and the ductility was actually lower in the $^1/_2$-in. specimens than in the 1-in. specimens. This effect may be due to the constant notch depth and its changing relation to the total test thickness.

Additional specimens of U and KA, KB,

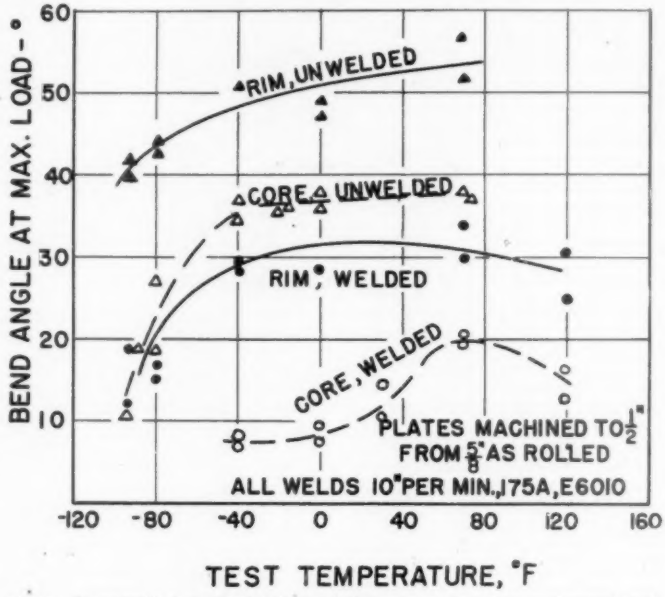

Fig. 7. Longitudinal notch bends notch in rim vs. notch in core rimmed steel, 0.26% C

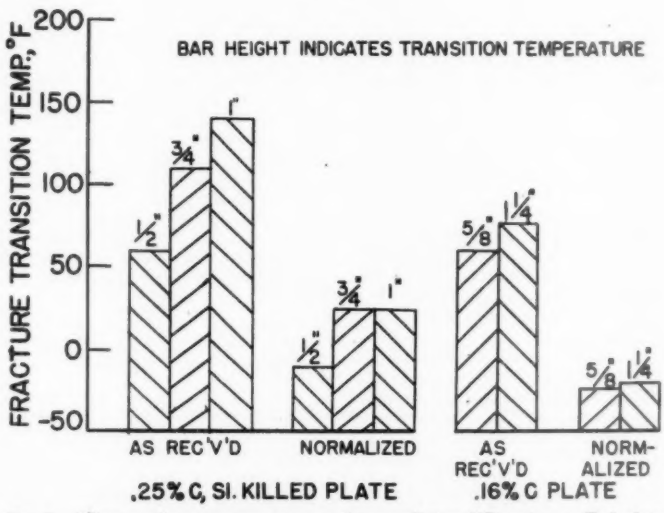

Fig. 8. Effect on fracture appearance of normalizing different as-rolled plate thicknesses from same heats. Tested in as-rolled thickness

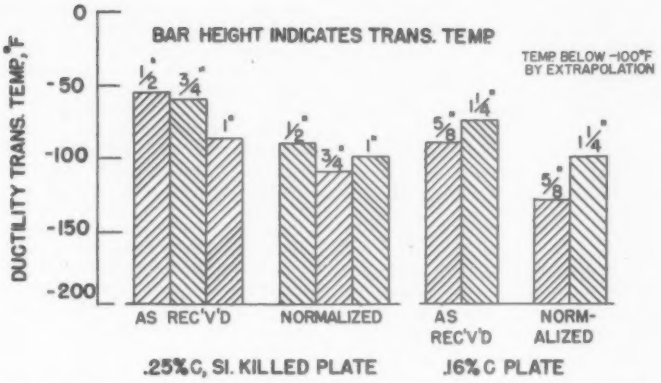

Fig. 9. Effect on ductility of normalising different as-rolled plate thicknesses from same heats. Tested in as-rolled thickness

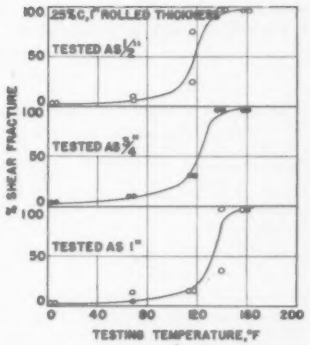

Fig. 10. Effect of specimen thickness on fracture transition temperature

KC were normalized 1 hr. at 1650° F. to alter the metallurgical structure. Figures 8 and 9 show that considerable improvement was obtained by normalizing, and the effect of thickness was noticeably reduced.

Normalising

The influence of normalizing on notch sensitivity has already been presented in Figs. 2, 3, 8 and 9. Some additional steels were normalized 1 hr. at 1650° F. to learn if normalizing provides consistent improvement. In Fig. 12, all of the steels are shown to be benefited by the treatment. The carbon content continues to exercise a strong controlling influence on the fracture transition after normalizing.

Welding

The contrast between ductility and fracture as criteria of transitional behavior becomes most striking when unwelded and welded plates are compared. Figures 2 and 3 illustrated this fact as did a series of tests reported previously.[3] A table from the previous report is reproduced in Table 3 for convenience. It is these data, as well as results on postheating presented just below, that have prompted the discussion of ductility and fracture to be found in a following section.

Postheating

The use of postheating at 1200° F. to avoid reduced properties in the weldment is so well established that one would not think to question its value. Yet if one examines the data contained in Figs. 13, 14 and 15, in which the fracture transitions of as-welded plates are compared to those of welded and postheated plates of KA, H and BF steels, it is found that the fracture transition temperature has actually risen after postheating. On the other

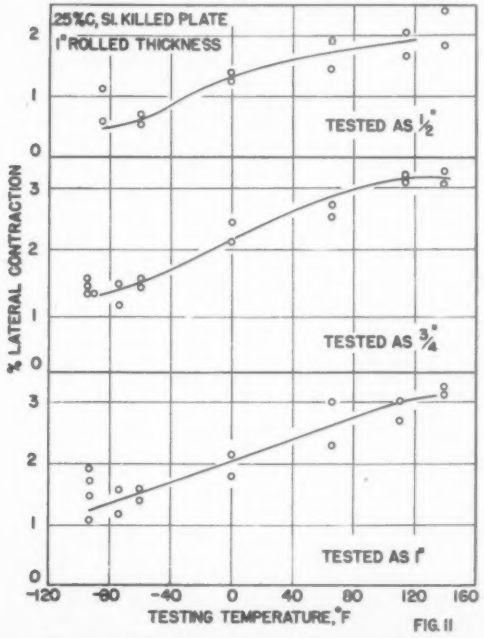

Fig. 11. Effect of specimen thickness on ductility

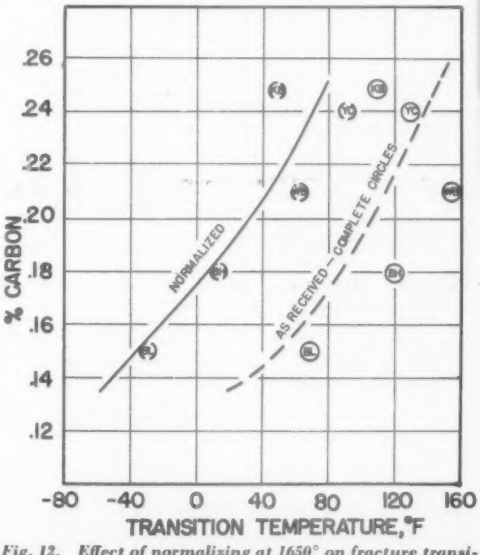

Fig. 12. Effect of normalizing at 1650° on fracture transition temperature

Table 3—Transition Temperatures of Prime Plates and Welded Plates by Lehigh Longitudinal Notch Bend Test

	Bend Angle Criterion, °F.		Fracture Criterion, °F.	
	Prime Plate	Welded	Prime Plate	Welded
0.21 C rimmed, normal	−65	50	120	140
0.21 C rimmed, as-rolled	−50	10	160	175
0.15 C semikilled, as-rolled	−70	0	−20	10
0.15 C semikilled, normal	−90	30	−25 (?)	40
0.25 C semikilled, as-rolled	−20	150	130	150
0.18 killed, as-rolled	−75	40	50	45
0.18 killed, normal	−15	55	50	50
0.14 C Mn-Ti, as-rolled	−95	55	0	50
0.15 C Mn-Ti, as-rolled	−60	80	100	85
0.23 C Mn-Ti, as-rolled	−10	105	100	110

NOTE: All welds were deposited with 3/16-in. E6010 at 175 amp. and 10 in./min. travel speed. All plates were 3/4 in. thick. The bend angle transition temperature was selected as that temperature where the bend angle had fallen to 10° at maximum load. The fracture transition temperature was determined by the appearance of 50% cleavage failure in the cross section.

hand, these figures show that the ductility transition of these same steels is lowered 50 to 100° F. by postheating. Which effect is really significant?

Straining and Aging

A few tests were run on KA steel to observe the changes in fracture and ductility transition temperatures brought about by straining and aging. Specimens were strained by bending them 20° in the test jig and then restraightening them before locating the notch at the locus of bending. The notch was placed on the side of the plate originally bent in tension. Tests were conducted on plates aged one week at 75° F., on another series heated 4 hrs. at 400° F., and on a third series heated 1 hr. at 1200° F.

In Fig. 16 the fracture transition is found to be raised by the strain-aging, most of all after heating to 1200° F. In Fig. 17, the ductility transition is raised strongly by straining and aging at 75 and 400° F. but is virtually restored to that of prime plate by the 1200° F. treatment.

The behavior of the fracture transition after heating to 1200° F. must be discounted, since the same phenomenon appeared in unstrained plate given this treatment. See Fig. 2 to confirm this.

Ductility vs. Fracture as Transition Criterion

In numerous parts of this report, the contrast of results obtained from the use of ductility measurements and of fracture observations has been drawn repeatedly. Since they so often are in disagreement, it is pertinent to consider which of them may be more significant to the service properties of steel. This will be done not with the hope of reaching an answer, but rather with the intention and hope of provoking further thought on the subject.

Recently a large number of investigations have been undertaken to develop testing methods which will reproduce service conditions and thereby make possible the selection of steels which are suitable for a particular service. One of the serious obstacles to such a goal is the question of deciding which properties actually determine service performance. At present, it is not known whether strength, ductility, energy absorption, mode of fracture or some other property is the one of significance. The fallacy of comparing test results between programs in which unlike properties have been measured has been pointed out previously.[3]

Structural Design Properties

In the design of most structures, a strength factor (elastic limit, yield or fatigue) of the material is the only property whose numerical value is utilized to arrive at the proper dimensions and arrangement of the members. At the same time, however, it has been recognized that suitable material cannot be guaranteed without some specification with respect to ductility. A given value of ductility can seldom be justified except that experience seems to indicate that lower levels of ductility would be hazardous. The tensile test has served almost exclusively for this measurement, although its shortcomings are freely admitted, so that in many cases it has been supplemented by notch-bar tests at operating temperatures. The importance of the ability of the metal to deform without rupture has been recognized for structures even though any general deformation would render the structure useless.

Because the tensile test fails to provide for the effect on ductility of combined stresses and of testing temperature that

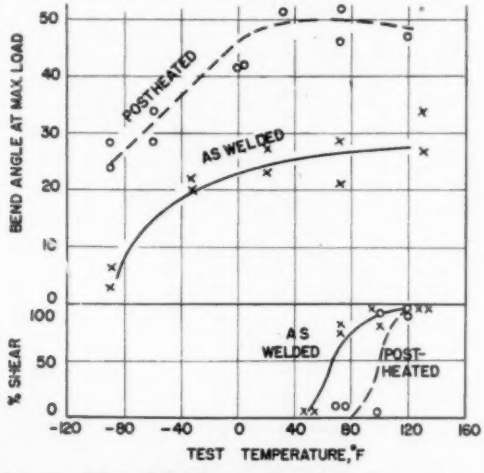

Fig. 13. Effect of Postheat on Transition Temperatures. 0.26% C, rimmed steel, 5/8-in. plate welds at 10 in./min., 175 amps., E6010 postheating 4 hr. at 1200° F.

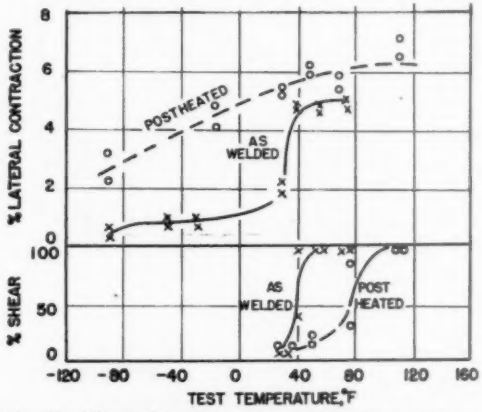

Fig. 14. Effect of postheat on transition temperatures. BF steel—0.18% C, 0.73% Mn, gr. size 5–7, 3/4-in. plate welds at 10 in./min., 175 amps., E6010 postheating 4 hr. at 1200° F.

are involved in actual structures, there has been considerable effort made to find testing methods which will furnish these necessary conditions. At the moment we suffer not from a lack of such specimens but from an inability to decide which ones are the most useful and how they can be applied to the problem.

Recently the failure of a considerable number of ships and pressure vessels under conditions in which rupture was violent and the fractured surfaces were granular or "sugary" in appearance has led to studies[5, 6] in which the mode of fracture has received emphasis. Here the tendency of the steel to change its mode of fracture from shear to cleavage type, as the testing temperature is lowered, is assumed to be the property of real significance.

Now it happens that the ductility of a steel and its mode of fracture are not at all susceptible in the same degree to the influence of testing temperature and stress distribution. It is possible to develop cleavage failure in steel after considerable deformation has taken place.[5, 6] The question then arises: which of these properties is significant in service? Will a steel capable of considerable deformation in a given structure be satisfactory even though its fracture, if finally brought about, is cleavage in nature? An attempt will be made here to present the evidence supporting each of these criteria of notch toughness.

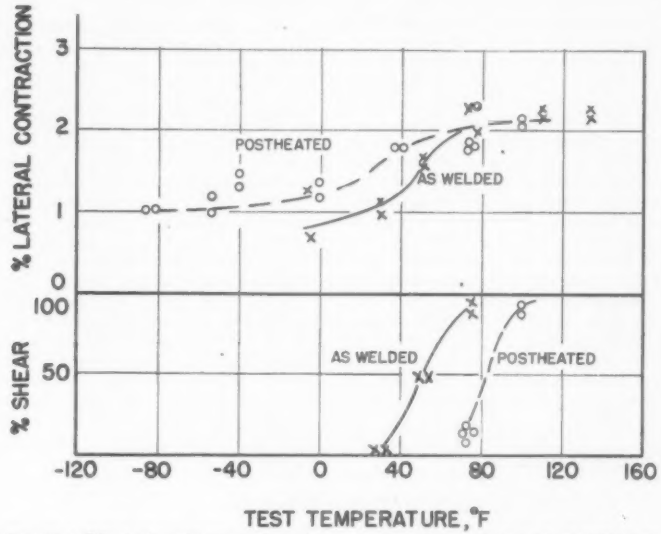

Fig. 15. Effect of postheat on transition temperatures. KA steel—0.25% C, Si killed, 1/2-in. plate welds at 10 in./min., 175 amps., E6010 postheating 4 hr. at 1200° F.

Ductility

The action of ductility in supplying resistance of a structure to failure has been described something as follows: If stresses were always introduced into a structure in uniform distribution, the strength alone of the material would suffice to determine its resistance to rupture; but because of concentrations involved inevitably by notches and changes of section, there are always localized areas in which the stress level is considerably higher than the

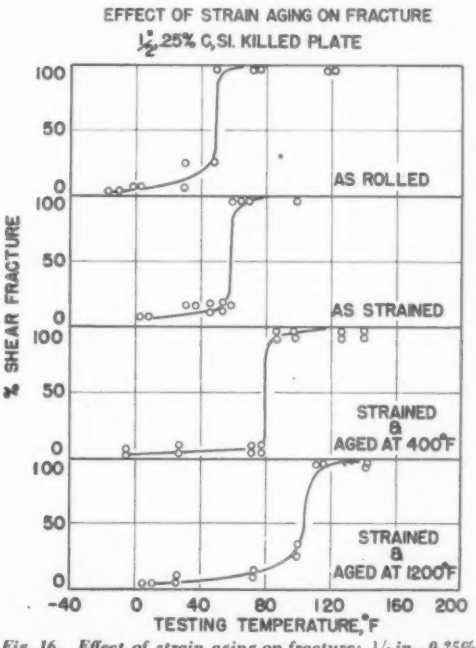

Fig. 16. Effect of strain aging on fracture; 1/2 in., 0.25% C, Si killed plate

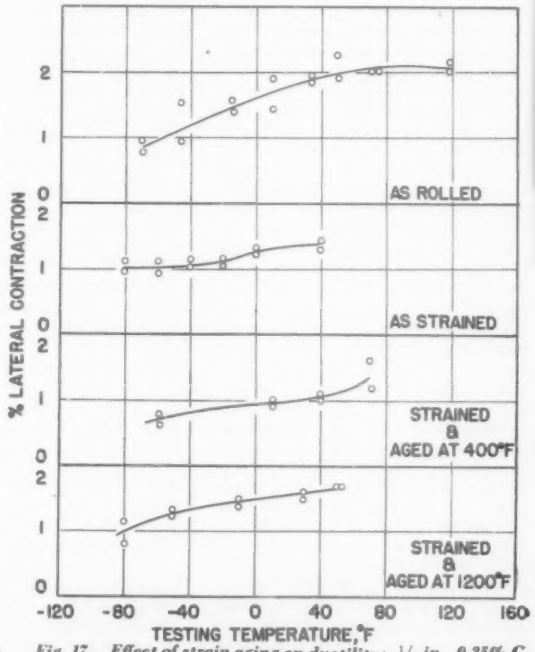

Fig. 17. Effect of strain aging on ductility; 1/2 in., 0.25% C, Si killed plate

nominal value. Only if plastic flow is possible, can these localized stresses be relieved and failure at these points averted. In many cases, the metal in a highly confined zone may be required to deform drastically, while the structure, as a whole, may not change dimensions to any measurable extent. Thus, it is not the plasticity of the whole structure, but rather the plasticity of critical local areas, that will determine the serviceability of the steel.

If the situation described above holds true for steel structures, then it would appear that ductility under combined stresses, rather than mode of fracture, is what really matters.

Examination of service failures in structural steels has brought out two facts. First, the fracture is almost always cleavage in appearance. But second, the ductility, as measured by reduction in thickness, has been very low, usually less than 1%. Now it happens that the transition temperature, as indicated by a sharp drop in ductility values, is always lower (at least, never higher) than that indicated by a change from shear to cleavage fracture. Thus, a steel member that has failed because of low ductility at operating temperature will always show a cleavage fracture. The assumption has been made frequently that the tendency toward cleavage failure is responsible for failure. Actually, cleavage failure may be just an accompanying phenomenon and not, in itself, indicative of inadequate steel properties.

Undoubtedly, there are a large number of structures in successful operation today at temperatures and under stress patterns which would result in a cleavage type fracture if failure occurred. The ductility of the steel may be responsible for allowing the structure to adapt itself to the load and thus avert failure.

In a report[7] prepared by a board of investigation appointed by the Secretary of the Navy, the failures of welded merchant vessels were studied in detail. In Table 11 of that report, it is indicated that the Charpy value of the fractured steels was almost always 10 ft. lb., or less, at the temperature of fracture. This energy value in the Charpy bar is known to correspond to a very limited ductility in the steel.

In Fig. 26 of the same report, the relation of fracture frequency to operating temperature is shown. At temperatures below 30° F. the incidence of fractures rises sharply. Tests of ship steels, such as in the wide plate tests,[5, 8] have demonstrated that cleavage failures in steels of this general type are to be expected in a range of temperatures extending well above 30° F. Thus, the transition temperatures indicated by ship failures do not appear to coincide with the transition temperatures indicated by cleavage failure.

Another investigation[9] of ship steels, in which the influence of hatch corner design was examined, brings out another point. By notch-reducing changes in the design, it was found possible to bring about great improvement in the behavior of the hatch corners. Yet both the worst and the best designs failed with a cleavage fracture. The elimination of poor performance of the hatch corners was not accompanied by elimination of cleavage fracture.

In laboratory specimens, a change in the design of the notch has been shown to affect the ductility of the steel far more than its tendency toward cleavage fracture. Likewise, welding conditions have much greater influence in changing the ductility transition temperature than the cleavage transition temperature. Moreover, postheating was shown to restore considerable ductility to welded steel, yet it changes the cleavage tendency very little. In at least four steels, postheating has been found to raise the fracture transition temperature. The response of ductility values to these operations is more in keeping with our experience with what notch severity, welding and postheating do to steel than is the response of fracture behavior.

Mode of Fracture

To parallel the discussion of the section above on ductility the behavior of a structure as controlled by its tendency to cleavage failure can be pictured in the following way. All steel structures contain notches, imperfections and incipient cracks which are potential sources of failure. The ability of the steel to resist the propagation of these cracks determines its serviceability. High resistance is indicated by shear fractures, which absorb large amounts of energy and proceed slowly. Low resistance is indicated by cleavage fractures which occur at extremely high velocities and absorb very little energy during their progress. If a structure does not fail at temperatures which can produce cleavage fracture, it is because the stress level never reaches the critical value required to propagate a crack. The strong influence of design is explained by the lowering of stress concentrations at strategic locations.

The criterion of cleavage fracture possesses several characteristics which recommend its selection as a logical criterion of the serviceability of steel. It is easily measured without special equipment. The transition from shear to cleavage fracture is usually fairly sharply defined on the temperature scale. There is almost no problem in deciding the level of performance which sets the transition, since the fracture changes from mostly shear to mostly cleavage within a distinct range of temperature, although there is frequently a scatter range in which either can occur.

These points, however, are relevant to the convenience of the criterion more than they are to its significance.

Even though a steel can absorb considerable energy before failure, the fact that it fractures suddenly and violently gives the impression that its behavior is dangerous and undesirable. Especially where personnel are involved, this may well become a determining factor.

It has been shown in Figs. 2 and 3 that in the presence of welding procedures involving high cooling rates and thus brittle metallurgical structures in the heated zone, the ductility transition temperature is raised to a level which is virtually the same as the fracture transition. There is good reason to believe that the mode of fracture is a reflection of the behavior of the steel in the presence of an infinitely sharp notch. Therefore, the fracture transition will indicate the temperature at which the steel will become unreliable when either welding or design or mechanical imperfections introduce extremely severe stress conditions. The fracture transition temperature then becomes a floor, representing the notch sensitivity of the steel under maximum constraint. This may be a logical condition to maintain in tests where steels are to be compared. However, the relation that it will bear to service conditions is a moot question.

Conclusions

From the discussion above, it is evident that no definite choice exists between the criteria of ductility and type of fracture as measures of service performance. Until information can be collected which will define the properties controlling the serviceability of steel, there can be no final answer to the problem. One possibility is to obtain steel samples from satisfactory and unsatisfactory pressure vessels and ships and then test these steels by means of laboratory specimens. It may then be possible to compare laboratory results with service behavior, at least to the extent that correlation or lack of it can be demonstrated for ductility or fracture type versus service properties. Such a project could furnish extremely useful data.

SUMMARY

The results of the investigation reported here can be summarized as follows:

1. Initial cracking appears in either prime or welded plate at relatively small angles of bend. If steel containing about 0.18% C and no alloys is welded, the first crack is found to appear in the weld metal. In steels of higher alloy or carbon content, it has always been found to form in the heated zone of the plate metal.

2. Normalizing at the proper temperature was shown to improve the fracture transition temperature of both prime and subsequently welded plate. The ductility transition temperature was improved somewhat in the unwelded plate and considerably in the subsequently welded plate.

Normalizing temperatures which are too high or too low were deleterious.

3. The longitudinal notch-bend test has been used to show the effects on fracture and ductility transitions of such factors as steel composition, plate thickness, welding, heat treatment and strain-aging.

4. The question of the relative significance of ductility measurements and observations of the type of fracture has been discussed. Advantages of each can be cited. Examination of satisfactory and unsatisfactory plates in service may provide the needed information for an answer to this problem.

ACKNOWLEDGMENT

The project reported here has been carried out under the auspices of the Welding Research Council. The authors appreciate the invaluable guidance provided by the Subcommittee, including R. E. Somers, Chairman, and Messrs. Aborn, Adams, Boardman, Jennings and Kinzel. They are very grateful, also, for the advice and encouragement of W. Spraragen and Dr. G. E Doan.

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Residual Stresses Due to Welding

Welding stresses are due to plastic deformations. Under static loading conditions residual stresses do not affect carrying capacity if yielding takes place. Brittle failures generally due to faulty design and poor material

by R. Weck, Ing., PH. D.

SYNOPSIS

Residual stresses can arise only from a geometrically noncompatible system of initial deformations. These are the plastic deformations introduced in certain forming operations. Welding stresses also are due to plastic deformations. Additional stresses may arise from the volume changes accompanying phase changes. If brittle constituents are formed or the plasticity is limited, cracking may occur. This is understood as arising directly from any geometrically noncompatible system of strains.

The plastic deformations and the residual stresses occurring in mild steel plates joined by a butt weld were measured with the Tomlinson strain gage in the immediate vicinity of the weld. The stresses were found to be near the yield point, and the opinion is expressed that stresses of this magnitude would always be found in welded steel. Welding procedure was found of little influence on the magnitude of the stresses. The restriction of angular distortion produced the highest stresses.

Very high stresses were produced by restraining the ends of the specimen in a stiff frame during welding. Cooling of the specimen relative to the frame resulted in still higher stresses which, together with the residual stresses, exceeded the yield stress. Although the steel was notch-brittle at a temperature 46° C. above the lowest temperature reached, yielding accompanied by stress relief still took place. The opinion is expressed that under static loading conditions the strength and carrying capacity will not be influenced by residual stresses if yielding takes place. Brittle failure which is sometimes ascribed to residual stresses appears to be due to faulty design and unsuitable material. There is evidence to suggest that the fatigue strength may be affected by residual stresses, but this question requires further investigation.

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INTRODUCTION

METALS are frequently found to be in a state of stress after they have been subjected to certain working processes, such as rolling, straightening, extruding, pressing, etc. It is generally recognized that these residual stresses are due to the plastic deformations which have been introduced in these forming operations. It is not generally appreciated, however, that the residual stresses present in a welded component when welding has been completed and the article has assumed its original temperature must also arise from plastic deformations. This can best be seen from a brief consideration of a mathematical criterion of the general conditions from which residual stresses arise.

In the theory of elasticity the state of strain of a solid body is described by six strain components and these, considered as continuous variables, must satisfy six partial differential equations, which are known as the compatibility conditions. The values of the six strain components at any point describe the deformation of a small elementary cube at that point, and the compatibility conditions simply express the interdependence of the strain components necessary in order to preserve the continuity and coherence of the solid.

It can be shown that residual stresses can only arise if there is an initial state of deformation present which is described by strain components not satisfying the compatibility conditions.

In this way thermal stresses, for instance, arise from the thermal dilatations. Three of the six strain components for thermal strains are zero and three are proportional to the temperature, and it can be shown quite readily that such a system can only satisfy the compatibility conditions if either the temperature is uniform for all parts of the body or the temperature gradient is linear. For all other temperature distributions thermal stresses must arise.

ORIGIN OF WELDING STRESSES

It would be quite wrong, however, to consider welding stresses simply as a form of thermal stresses. The stresses which are of interest are the stresses present after welding has been completed and after the body has reached uniform temperature. Since there is then no temperature gradient, there can be no thermal stresses.

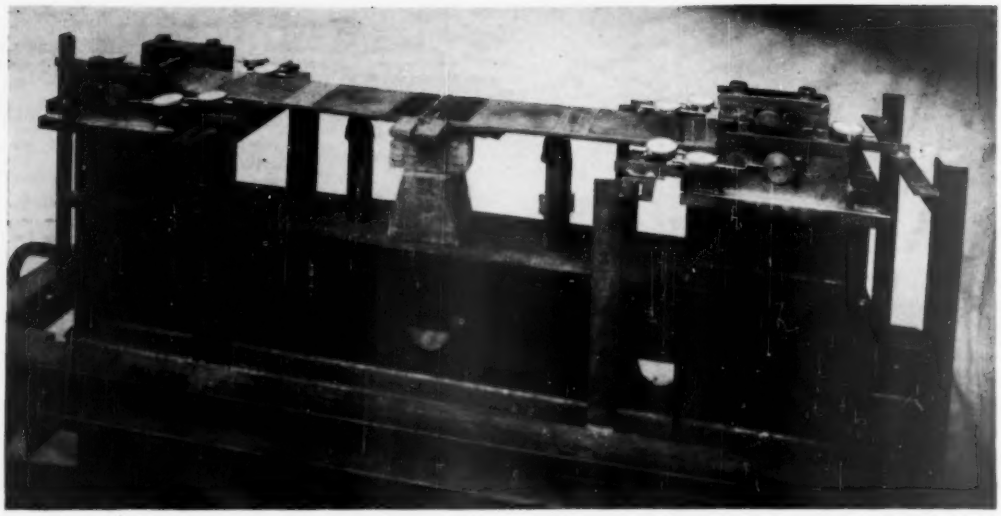

Fig. 1 Restraining frame with specimen after welding

The dial gages measure the deflection of the frame and this is a measure of the load introduced into the specimen in consequence of transverse weld contraction and end restraint. In this particular experiment these end loads corresponded to average stresses of 2½ tons per square inch. Very much higher stresses were found in the vicinity of the weld. These were measured with the Tomlinson gage. The gage marks are clearly visible in the photograph

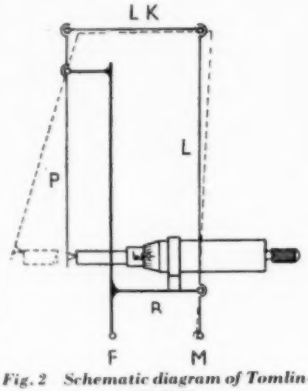

Fig. 2 Schematic diagram of Tomlinson gage

Very severe thermal stresses must arise during welding from the severe nonuniformity of heating. These thermal stresses will produce large plastic deformations, especially in materials such as low-carbon steels, whose deformation resistance is small at high temperatures. These plastic deformations, together with the thermal deformations, form a compatible system, but after cooling to uniform temperature the thermal strains disappear and the plastic deformations remain. These remaining plastic deformations by themselves, however, will not satisfy the compatibility conditions and they form the source from which residual welding stresses originate.

In a joint made between two low-carbon steel plates, by electric arc welding, for instance, these plastic deformations are found in a zone of approximately 3 in. width at both sides of the weld, and their over-all effect is the longitudinal and transverse weld shrinkage known to all welding engineers.

Residual stresses cannot arise unless there is material which is more or less severely plastically deformed. The question, therefore, whether residual welding stresses give rise to plastic deformations is rather inappropriate, since the material must be plastically deformed first before residual stresses can arise. It is extremely difficult to say, however, at what temperature in a particular region the process of plastic deformation comes to an end. It is possible that part of the plastic deformation takes place at temperatures below 600° C., and that strain aging may occur in consequence. In this way some of the effects attributed to residual stresses may in fact be attributable to strain aging.

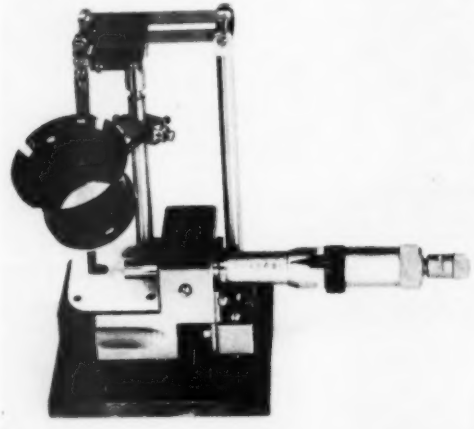

Fig. 3 Tomlinson strain gage

The change in the distance of two conical gage marks 1 in. apart is transmitted to a pointer, the movement of which is measured by a micrometer

WELDABILITY

The résumé would be incomplete without referring to one aspect of the problem of weldability which is intimately connected with the question of residual stresses. So far, we have considered an ideal material which does not undergo phase changes, or whose phase changes are not accompanied by volume changes, and whose plasticity at higher temperature is unlimited.

Phase changes are inevitable in a number of important materials, in consequence of

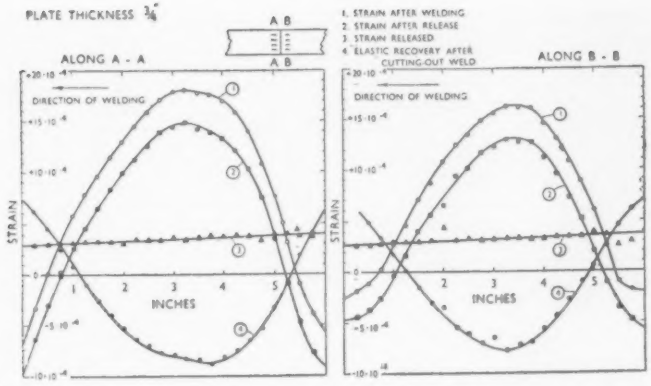

Fig. 4 Transverse strains, top of plate 1 1/2 in. from weld

the heat applied in the welding process. If the volume changes accompanying phase changes took place simultaneously throughout the entire material, no other residual stresses than those already considered would occur. There may be tessellated or microstresses in consequence of the formation of different constituents, but consideration of these falls outside the scope of this paper.

The strains accompanying volume changes are of the same type as thermal strains, i.e., three dilatations and no shear strains. An important difference lies in the fact that thermal strains disappear after uniform room temperature has been reached, leaving incompatible plastic deformations which give rise to residual stresses while strains due to volume change will persist and form a compatible system with the plastic deformations which must accompany them.

Of course, in this case again no residual stresses will be found in addition to those considered already. If, however, the plasticity of the material is in any way limited at the time the volume change takes place; if, for instance, hard or brittle constituents are formed, the noncompatible system of volume-change-strains cannot be transformed into a compatible system by plastic deformation and cracking must result.

Cracking is a disruption of the continuity of the solid. This corresponds to multivalued displacements, and it was shown analytically by V. Volterra[1] that the displacements corresponding to a system of noncompatible deformations must be multivalued. From this we can say that a noncompatible system of initial deformations—arising from phase changes, for instance—which cannot be transformed into a compatible system by plastic deformations, results in multivalued displacements which are equivalent to disruptions of continuity, i.e., cracking.

MEASUREMENT OF DEFORMATIONS IN THE VICINITY OF THE WELD

Residual stresses could be calculated in the same way as stresses due to external loads if the magnitude and distribution of the plastic deformations from which they arise were known. These plastic deformations due to welding, however, are not known and cannot, in view of the complexity of the phenomenon, be deduced from first principles. The only other method available for evaluating the residual stresses is measurement. This can be carried out in one of several different well-known ways, all of which, apart from X-ray methods, involve subdivision and strain gages of one sort or another.

In an investigation* which the author was privileged to carry out under the direction of Prof. J. F. Baker at the University Engineering Laboratory, Cambridge, an attempt was made to measure not only the residual stresses but also the plastic deformations from which they arise. This required measurements in the immediate vicinity of the weld and an instrument had to be used which did not necessitate permanent fixing in place. But before describing this instrument which was a modified form of a strain-gage designed originally by the late Dr. G. A. Tomlinson of the National Physical Laboratory, it might be well to consider briefly the general arrangement of these experiments.

A U-shaped frame (Fig. 1) was constructed from rolled sections. This frame was used to restrain the ends of a mild steel specimen consisting of two 6-in. wide strips which after placing in the frame were joined by a butt weld. The contraction taking place across the weld caused a deflection of the vertical members of the frame proportional to the total load introduced into the specimen by welding under exterior restraint. This deflection was measured by dial gages and was proportional to the average stresses in the plate. These were approximately 2 1/2 tons per square inch in this particular set of experiments, and did not vary very much with either plate thickness or welding procedure.

Considerably higher stresses existed in the vicinity of the weld where the stresses due to the end loads were superimposed on residual stresses of considerable magnitude. These were measured with the Tomlinson gage, and some typical results are reproduced in Figs. 4 and 5.

In the Tomlinson gage use is made of the same principle of mechanical magnification as in the Huggenberger strain gage. This is shown diagrammatically in Fig. 2. The gage itself is shown in Fig. 3.

The two pegs (*M* and *F*, Fig. 2) are 1 in. apart and carry 1/32 in. diam. steel balls at their ends, which register in conical punch marks defining a 1-in. gage length. It is essential for these gage lengths to be

* This investigation was carried out for the Admiralty Ship-Welding Sub-Committee of the British Welding Research Assn., and the author wishes to make due acknowledgment for permission to use some of the information obtained.

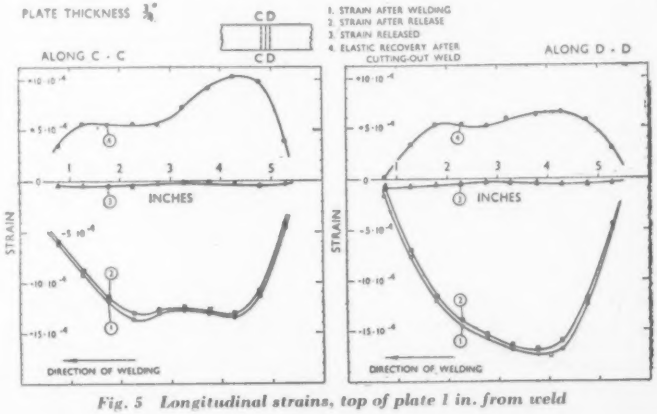

Fig. 5 Longitudinal strains, top of plate 1 in. from weld

Fig. 6 Restraining frame consisting of two columns 4½ in. diam. connected to the two circular disks to permit rotation

The specimen shown in position ready for welding is supported on wedges. The clamp at each end keeps specimen and wedges in position prior to welding. Electrical strain gages are attached to the columns at the middle for the measurement of the column load. Also note gage marks for the Tomlinson strain-gage measurements

marked out very accurately, for the total range of movement of the gage is only about 10×10^{-3} in. The marking out of the gage lengths is best done in a milling machine.

When the two pegs are arrested in the gage marks, the position taken up by the pointer is measured by a micrometer which is fixed to the gage. The gage can then be removed. Any change in the gage length can then be measured by registering the two pegs in the gage marks and, since the pointer will assume a different position, a different reading is obtained. The difference between the two micrometer readings is proportional to the strain.

The curves *I–IV* in Figs. 4 and 5 were obtained by taking readings before welding, after welding, after release of the specimen from end restraint and after cutting out the weld. Hence Curve *I* represents the total strains due to welding; it includes the plastic deformation and the strains due to residual stresses. Curve *III* is the elastic strain released after relieving the specimen from end restraint. Curve *II* is the difference between curves *I* and *III* and is the sum of the strains due to residual stresses and to plastic deformations from which they arise. Curve *IV* is the elastic recovery taking place after cutting out the weld and this is approximately proportional to the residual stress. It can be seen that the sum of the residual stresses and the stresses due to end restraint in the center of the plate 1 in. away from the weld was found to be near the tensile yield stress of the material. This is quite a typical result for mild steel plates welded up under moderate restraint.

The relaxation obtained by cutting out the weld shows that the major part of the plastic deformations is located in the weld and a narrow zone of the adjoining parent metal. This follows from direct measurement of the contraction of the weld transverse to its direction, which varied for different plate thicknesses between 20×10^{-3} in. and 80×10^{-3} in. and also varied along the weld. The difference between curves *II* and *IV* can be considered as the plastic deformations taking place transverse to the direction of the weld in a 1-in wide strip 1 in. away from the weld.

The investigation had been undertaken with the object of determining the influence of different welding procedures on the magnitude of the stresses arising on consequence of exterior restraint and it was found that they had little, if any, influence. Other factors were found to be much more important; the highest stresses were produced when the angular distortion was restricted. The investigator formed the opinion that in the application of electric

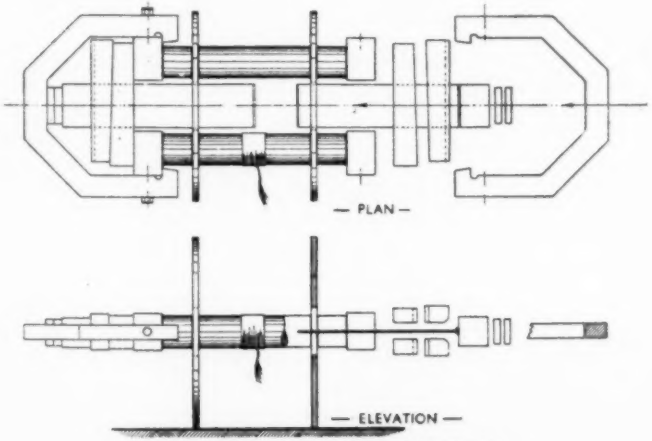

Fig. 7 Arrangement of restraining frame

are welding to low-carbon steel, stresses up to the yield point could probably always be detected somewhere; or, at all events, quite impracticably meticulous precautions would have to be taken in order to keep the residual stresses everywhere below the yield point of the material.

THE INFLUENCE OF RESIDUAL STRESSES

If we have to accept the fact that arc-welded steel will always contain residual stresses which may be near the yield point of the material, the question as to how these residual stresses affect the strength and carrying capacity assumes great importance. There is little evidence in the literature on which a definite answer could be based. To cite just a few comparatively recent and authoritative utterances on this question: G. Sachs[3] states: "The residual stresses in fusion-welded structures are generally considered to be deleterious. (This has not been proved as yet)." Rös[3] of Zürich says: "If there are no discontinuities in the structure in the form of fine cracks, then these additional stresses are normally without practical significance provided the material is sufficiently ductile." Stüssi,[4] on the other hand, comes to the conclusion, on the basis of experimental work, that "shrinkage stresses influence the fatigue strength of welded joints." Bohny and Busch[5] state, in conclusion of a report on work with stress-relieved and not stress-relieved welded plate girders, that "The safety of welded steel structures against fracture is increased by stress-relieving heat treatment. . ."

In the course of the investigations already mentioned, some results were obtained which are not without significance.

A second restraining frame of very much higher rigidity was constructed (Figs. 6 and 7) in order to produce more severe restraint and higher stresses. The total load introduced in the 6-in. wide specimen by a butt weld deposited when the ends of the specimen were restrained in the frame could be determined by measuring the total compression load in the frame with electric resistance strain gages. This, of course, was equal to the load in the plate, and the average tensile stress in the plate could be determined from these measurements. The residual stresses and the plastic deformations near the weld were again measured with the Tomlinson strain gage.

Figures 8 and 9 show typical results. The shape of the curves is similar to that shown in Figs. 4 and 5, but the magnitude of the strains, especially those introduced by restraint, is considerably higher.

In some of the tests the specimens were, after having cooled to room temperature packed in solid CO_2. This had the double objective of raising the average stress in the plate still further—the plate in cooling contracted relatively to the frame—and of

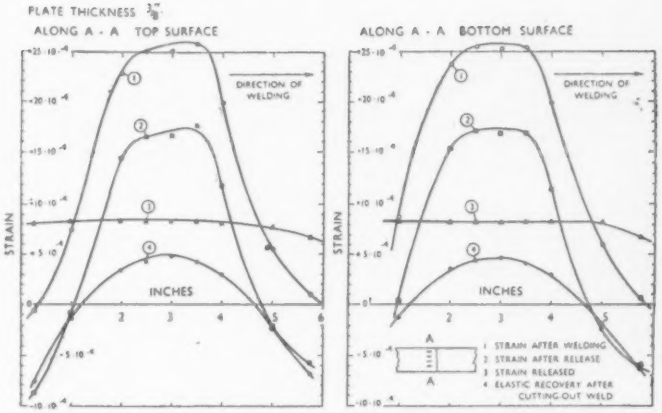

Fig. 8 Distribution of transverse strain across plate at 1½ in. from weld

lowering the plate temperature to below transition temperature.

The transition temperature of one particular specimen was +8° C.* A stress due to end restraint of 11 tons per square inch had been introduced and, in addition, there was a residual transverse tensile stress near the weld of at least 5 tons per square inch. The specimen was cooled to −38° C. This increased the average stress from 11 to 16 tons per square inch. Adding to this the residual stress of 5 tons per square inch, a maximum tensile stress of 21 tons per square inch was reached, certainly higher than the room temperature yield stress of the material (18 tons per square inch). In addition, there was, of course, a longitudinal residual stress, the magnitude of which had not been determined. The specimen was held at this temperature for perhaps 30 min. When it had resumed room temperature the average stress, as measured by the load in the columns, had dropped to 8.5 tons per square inch. That is, in the cooling cycle a stress relief of 2.5 tons per square inch by yielding under the influence of residual stresses had taken place 46° below the transition temperature. It would not have been surprising from the evidence of recent work[6] on the brittle fracture of mild steel if the plate under this treatment had fractured suddenly. But fracture did not take place in this or in any of a large number of other tests designed to create what might be considered very unfavorable conditions of stress, form and temperature. This is reassuring, though it does not, of course, prove that residual stresses have no deleterious effect.

There are two ways in which the static strength and carrying capacity of a

* The transition temperature at which the tensile fracture of a notched testpiece changes from a ductile to a cleavage type of fracture was known from work carried out by Dr. C. F. Tipper, at the University Engineering Laboratory, Cambridge.

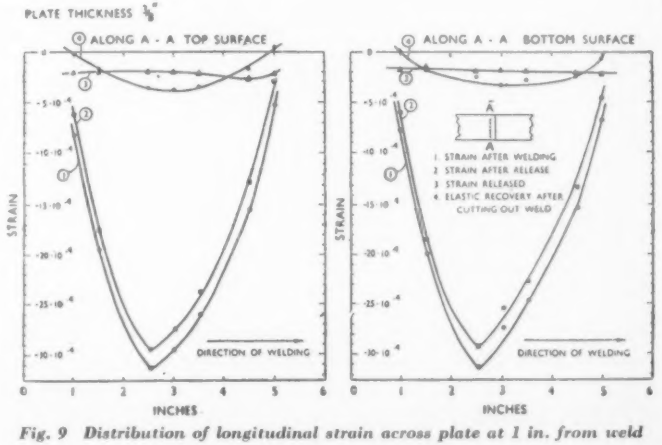

Fig. 9 Distribution of longitudinal strain across plate at 1 in. from weld

welded structure can be conceived to be affected by residual stresses. One is the occurrence of yielding at applied loads of lower magnitude than those which would produce the same effect in a stress-free structure. The other conceivable way in which residual stresses are sometimes thought to affect welded structures is that of facilitating or producing brittle failure.

The first effect has not worried engineers in the past, when using material such as rolled sections which were afflicted with residual stresses from the process of their manufacture. It is only right that it should not worry them now when the stresses are due to welding. Local yielding will, of course, occur, but, since the character of a self-balancing system of residual stresses must always be different from that of a system due to external loads it is inconceivable that these two systems might ever be superimposed in such a way that the stresses would be additive everywhere. If they are additive in one place, they must needs subtract in another. The collapse load under static loading would be unaffected, for progressively more load could be taken by the parts which are understressed as the overstressed parts yield, and as they yield, the residual stresses will be relieved.

The other type, i.e., brittle failure, if it occurs, is of grave concern to engineers. There is no definite laboratory evidence, however, that residual stresses may give rise to brittle failure, though certain practical experiences with welded bridges and welded ships seem to be strong evidence in support of this contention. But what evidence there is seems to point more to unsuitable material and faulty design as a cause than to residual stresses.

There are strong indications that the fatigue strength of a structure or component may be affected by residual stresses. This question requires further extensive investigation. A carefully planned, long-term investigation of this problem has been initiated, and is now being carried out by the British Welding Research Assn.

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Arc Phenomena with Electrodes Moving at High Speed†

Discussion by L. H. Orton* and J. C. Needham*

The present paper is of interest, as indeed is any paper which offers a technique for observing and studying the arc, and the further development and extention of the investigations here discussed should prove of importance.

The study of the steel rod to steel plate arc is one of some difficulty, for the usual arcing processes, complex in themselves, are disturbed by the additional factor of material transference. The authors of the paper state that their technique makes it possible for them, under certain circumstances, to maintain a stable arc and at the same time interrupt and repeat the arc process so that certain effects may be observed. Any technique which proves capable of yielding accurate and repeatable test results in relation to work of this nature is valuable.

There are, however, several matters in the paper on which we should like to comment briefly. These will not be dealt with in order of importance, but for ease of reference, in order of context in the paper.

Figure 4 shows a photomicrograph of a section through an anode spot on steel tape. Can the authors state the relationship of the contour there shown to that of the molten anode pool? Visual inspection of enlarged images of electrodes thrown onto a screen show that considerable contour changes, including the formation of a "peak" on the anode, can occur during cooling and solidification following the current cut off.

The oscillograms shown in Figs. 5 and 6 are of some interest. From general appearance it is assumed that the arcing voltage records were obtained using an electromagnetic type oscillograph, with, for this type of unit, a fairly high-frequency response. Work we have carried out in the laboratories of the Electrical Research Assn., in cooperation with the British Welding Research Assn., is in agreement with the authors' findings in relation to the high-frequency fluctuations superimposed on the arcing voltage. Care must, however, be taken that the upper frequency limit recorded is not governed by the response time of the recording unit. The authors state that frequencies of 1000 to 3000 cps. are present, with a voltage swing of 0.5 to 5 v., while they add that there is evidence of small variations in voltage at higher frequencies. The authors are correct in this supposition, since we have data (E.R.A., Report Reference Z/T72), to be published shortly, showing that oscillations of the order of 100 k. cycles per second are present for certain electrode conditions. In addition, some attempt is made to account for certain of the voltage fluctuations and oscillations, the causes of which are queried in the present paper.

In due course it is hoped that the authors will provide more detailed information in relation to their high-speed motion picture technique than it has been possible for them to include in the present paper. Reproduction of actual high-speed photographs would be very interesting, while further data as to filters and their effects on the apparent size and shape of the arc and its surround would be valuable.

In the section under Characteristics of Anode Spots, the authors state that the surface finish of the anode tape influences the frequency of the anode spots. It would be of interest to know details of the surface finish of the 1/4-in. diameter bare mild steel rod used as

(*Continued on page 40-s*)

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† The paper by W. B. Kouwenhoven and T. B. Jones was published in the Sept. 1948 *Research Supplement* to WELDING JOURNAL pp. 470-s to 475-s.

Further Studies in Projection Welding

The variables of weld time, current, electrode force, projection size and shape and their effects on weld properties for different steels are reported

by W. F. Hess, W. J. Childs and R. F. Underhill, Jr.

Summary

The projection welding of 0.040-in. A.I.S.I. 1010, 1015 and 1020 steels has been investigated. The variables of weld time, weld current, electrode force, projection size and shape and their effect on weld formation and strength have been studied. Projection diameters below 0.10 in. have proved unsatisfactory but the exact value of diameter in the range from 0.10 to 0.14 in. was not critical. Projection heights 20% of the diameter gave better results than lower projections. Higher resistance electrode materials have been found to require less welding current than low-resistance electrodes. A weld time of at least 10 cycles was required for consistent projection welds in 0.040-in. steels. The ratio of multiple to single weld strength decreased with carbon content in the 0.040-in. thickness steels.

INTRODUCTION

THE research reported in this paper is a continuation of the previous work which has been conducted at Rensselaer Polytechnic Institute. It has been undertaken in an effort to broaden the knowledge of projection welding and to establish optimum conditions for welding various types and gages of steel. This work has been conducted under the sponsorship of the Welding Research Council. Previous work has been done on 0.125- and 0.062-in. thickness gages. This report supplements the prior investigation in these thicknesses and in addition deals with the 0.040-in. gage of low-carbon steels.

EQUIPMENT

Two different welding machines were used for this investigation. A large 175-kva., motor-operated toggle, press-type welder, with provision for electrodes up to $2^1/_4$ in. diameter, was employed for making most of the welds in the thicker gages, particularly for the multiple weld specimens. For welding the thinner gage materials, better results were obtained with a 200-kva., air-operated machine which had a more rapid follow-up.

An electronic current regulator was used to maintain the current at any desired value. Current magnitude was measured by means of a strip-chart recording ammeter for the longer weld times. Shorter weld times were measured either by a pointer-stop ammeter or by placing a copper plate between the electrodes and increasing the weld time to a sufficiently long time to permit the use of the recording ammeter. The latter procedure could be followed only when the current regulator was utilized. The duration of current flow was checked by a precision synchronous electric clock for the longer weld times and either by a Brush direct-inking oscillograph or a magnetic oscillograph for shorter times.

MATERIAL

The material for this investigation was A.I.S.I. 1010, 1015 and 1020 in the 0.040-, 0.062- and 0.125-in. thicknesses. The composition and mechanical properties of these steels are listed in Tables 1 and 2. To obtain a clean uniform surface for welding, the steel was grit-blasted. This was necessitated by partial rusting of some of the material on shipment.

TESTING

The methods of testing the projection welds and the specimens used have been described in detail in a previous paper.[1] The normal tension and shear tests were used extensively throughout the investigation to study the effect of the different variables on the mechanical properties of the weld. A chisel test was used for preliminary examination of the weld to determine roughly the amount of fusion and the amount of adherence. Radiographs were taken to study the amount of porosity present and to evaluate the methods of eliminating the porosity.

Two pieces, 2 x 6 in., were used in making all of the shear and normal tension test specimens. The exact dimensions of the completed specimen and the location

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This paper was presented at the Twenty-Ninth Annual Meeting, A.W.S., held in Philadelphia, Pa., week of Oct. 24, 1948.

[1] Hess, W. F., and Childs, W. J., "A Study of Projection Welding," THE WELDING JOURNAL, 26 (12), Research Suppl., 712-s to 832-s (1947).

Table 1—Chemical Analysis

Item No.	Material, A.I.S.I. No.	Thickness, in.	C	Mn	P	S	Si	Cu	Ni	Cr
1	1010	0.040	0.08	0.36	0.007	0.028	0.012	0.04	0.06	0.05
2	1010	0.062	0.08	0.36	0.007	0.028	0.012	0.04	0.06	0.05
3	1010	0.125	0.08	0.39	0.010	0.027	0.010	0.06	0.05	0.03
4	1015	0.040	0.15	0.40	0.012	0.012	0.027	0.03	...	..
5	1015	0.062	0.14	0.54	0.014	0.035	0.010	0.011	0.011	..
6	1015	0.125	0.14	0.54	0.014	0.035	0.010	0.011	0.011	..
7	1020	0.040	0.20	0.45	0.012	0.042	0.003	0.01	...	..
8	1020	0.062	0.20	0.45	0.012	0.042	0.003	0.01	...	..
9	1020	0.125	0.20	0.45	0.012	0.042	0.003	0.01	...	..

of the projections has been illustrated in a previous paper.[1] This same specimen size was used for the multiple specimens. In the shear test, the pieces were overlapped 2 in. and the projections centered in the overlap. For the normal tension test, the same size pieces were used but the welds were placed in the center of an overlapping cross. Tension was applied perpendicularly to the sheets by means of a jig which was designed to minimize sheet slipping and distortion.

DIES AND PUNCHES

Spherical projections were used throughout this investigation. Dies consisted of spherical depressions formed in a die block by forcing a ball with the desired curvature into the block, followed by grinding down the flat upper surface until the required depth of depression was obtained. Punches were truncated cones with a 30° half angle. The height of the punch was chosen to be slightly greater than the desired height of the projection. Punch volume was calculated to equal the volume of the die depression. In thin materials, when greater projection rigidity is needed, the punch can be made a little higher and not so wide at the base. This design gives a greater resistance to collapse.

The dies and punches were made of an air-hardening steel and were hardened and tempered to a value of Rockwell C 60.

WELDING OF THE 0.040-IN. THICKNESS STEELS

In studying the projection welding of the 0.040-in. steels, most of the emphasis was placed on welding the lowest carbon, S.A.E. 1010 steel. This steel was chosen in preference to the higher carbon S.A.E. 1015 and S.A.E. 1020 steels because it was felt that the 1010 steel would be freer from difficulties introduced by hardening of the steel during welding. In a manner similar to that previously employed in investigating the welding of the thicker gage materials, the influence of projection diameter and height, weld time and current, weld diameter and electrode force were studied. The general procedure followed and the results obtained are outlined below.

Projection welds were made using spherical projections of 0.08-, 0.10- and 0.14-in. diameters with heights ranging from 0.007 to 0.025 in. These welds were sectioned and examined metallographically to observe the effect of the welding variables on weld formation. Normal tension and shear tests were also made on these welds to evaluate their mechanical properties.

Welding was first attempted on a large 175-kva. welding machine having a mechanically operated toggle. Although this machine was equipped with an aluminum head to minimize inertia, the follow-up characteristics were too slow to give good results in welding the 0.040-in. steel. The welds were quite erratic, showing inconsistency in both weld diameter and strength. Furthermore, these welds were not always symmetrical and porosity was excessive in almost all cases, even though the electrode force was raised to a fairly high value. This need for a rapid follow-up of the electrode during projection collapse was more particularly emphasized in this thin gage because of the shorter time involved and the consequent more rapid collapse.

More consistent results were obtained when welding was done on an air-operated machine which was of lighter construction although it was rated at 200 kva. The follow-up in this case was sufficiently more rapid to result in considerably better welds.

WELD TIME

In order to study the influence of weld time on the projection welding of steels in this gage, welds were

Table 2—Mechanical Properties

Item No.	Material, A.I.S.I. No.	Thickness, in.	Yield Strength, psi.	Ultimate Strength, psi.	Hardness Rockwell "B" scale	Elongation % in 2 in.
1	1010	0.040	...	45,350	50	32
2	1010	0.062	39,100	49,500	52	32
3	1010	0.125	40,700	43,600	52	30
4	1015	0.040	...	50,850	54	25
5	1015	0.062	40,300	53,200	59	32
6	1015	0.125	46,000	55,800	60	31
7	1020	0.040	...	51,030	52	27
8	1020	0.062	49,400	61,450	70	23
9	1020	0.125	46,650	60,200	70	27

made with 2-, 5-, 10-, 15- and 20-cycle weld times, utilizing a projection of 0.10-in. diameter and 0.025-in. height and an electrode force of 400 lb. The variation of fused zone diameter with welding current for different weld times is shown in Fig. 1. The welding current was varied from the point where there was no fusion to a condition in which metal expulsion or electrode adherence occurred. Very poor results were obtained with a weld time of only 2 cycles.

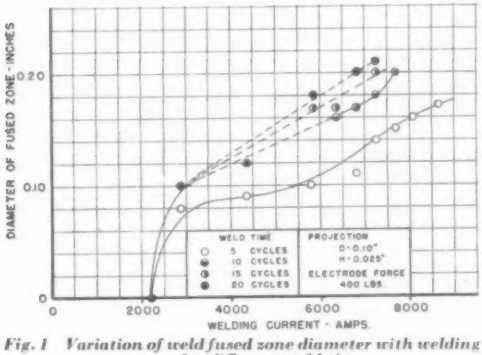

Fig. 1 Variation of weld fused zone diameter with welding current for different weld times

A few fusion zones were obtained with this weld time but only at very high current values. The excessively high current caused some surface melting, spitting, from between the sheets and irregular projection collapse. The resulting weld sizes and weld strengths were most erratic and unsatisfactory. Using a 5-cycle weld time, fused zones were produced at much lower values of welding current. These welds were a definite improvement over the 2-cycle welds, but the welds were still somewhat erratic in size, shape and strength. Evidently this weld time was still too short to allow for proper projection collapse and weld formation. Insufficient weld period does not permit the heat, which is initially generated primarily at the projection itself, to spread into the surrounding metal. This surrounding metal supports the embossed projection. During welding it should soften from the heat of the welding current, permitting the projection to collapse uniformly. Very short weld times also result in rapid projection collapse. If this collapse is too fast, the upper head of the welding machine will not be able to follow sufficiently rapidly and the necessary electrode force is not maintained throughout the welding period.

Welds made at weld times of 10 cycles or longer were much more satisfactory. Projection collapse was more even, the weld fused zones were more symmetrical and the weld strengths were more consistent with this longer time. The influence of weld time in the range of 10 to 20 cycles is not very appreciable. From Fig. 1 it can be seen that for a given weld current the size of the fused zone is not greatly increased as the time is increased from 10 to 20 cycles. This condition is desirable since it indicates that, within this range, a slight unintentional variation in the duration of the welding period would not greatly affect the size and strength of the resulting welds.

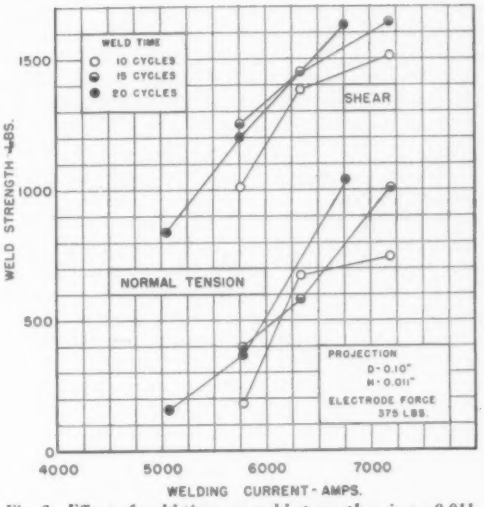

Fig. 2 Effect of weld time on weld strength using a 0.011-in. projection height

The effect of weld time on projection weld strength is shown for two different height projections in Figs. 2 and 3. For a given welding current, slightly higher strength is obtained with the larger welds resulting from the longer weld times. This is true both for the shear and normal tension tests in both projection heights. The welds made in 10, 15 and 20 cycles were all rather satisfactory with regard to consistency but

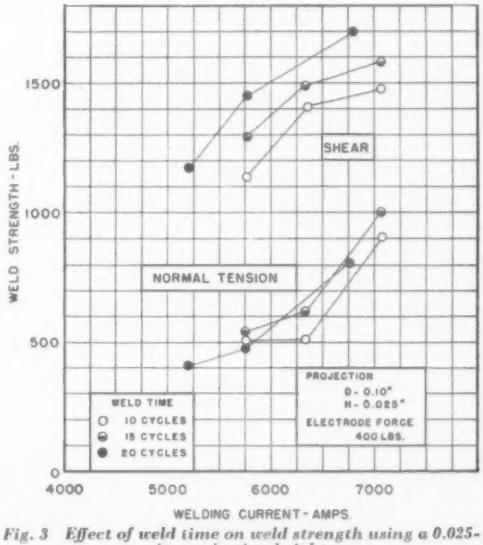

Fig. 3 Effect of weld time on weld strength using a 0.025-in. projection height

slightly better consistency was secured with a 15-cycle weld time as contrasted to 10 cycles. No noticeable improvement resulted from increasing the weld time to 20 cycles and since unwarranted extra time is objectionable from the standpoint of production schedules, a weld time of 15 cycles was selected.

PROJECTION DIAMETER

Projections having diameters of 0.08, 0.10 and 0.14 in. with varying heights in each diameter were welded in order to determine the effect of projection diameter on welding characteristics. The welds made using the 0.08-in. projection diameter were not satisfactory. They had lowered and rather erratic strengths. The fused zones tended to be insufficient in size and were not always symmetrical in shape. It was concluded after investigating the 0.08-in. diameter projection in heights from 0.007 to 0.022 in. that this diameter was too small for satisfactory projection welds in 0.040-in. steel.

Welds made with projections of 0.10 and 0.14 in. were much more satisfactory than the welds made with the smaller projections. These welds were much more consistent in fused zone, shape and size and also in weld strength. Within this range of projection diameters, the diameter was not especially critical, the consistency being fairly good for both values and the welds being quite symmetrical. In Fig. 4 the shear and normal tension strengths are plotted for welds made using 0.10 and 0.14-in. diameter projections. The height of both projections was 0.025 in. It can be seen that there is not great difference in strength for welds made with these two different projection diameters. It is especially interesting to note that the weld strengths obtained for these two projections with the same welding current did not differ greatly. In the thicker steels it was generally found that larger projection diameters required greater weld currents to achieve the same size welds and equal weld strengths. The ratio of normal tension to shear strength for the welds made with these projections is shown in Fig. 5. This ratio is an indication of the ductility of the weld which is a most important property to be considered. It can be seen that this ratio is quite low for small welds, increasing from about 25 to 50% with increasing welding current. This ratio is more constant over the major portion of the range for the 0.14-in. projection diameter than for the 0.10-in. projection. The shear and normal tension strengths for welds made using the 0.14-in. diameter projection are slightly greater than for the welds made with the smaller projection. For these reasons, the 0.14-in. projection was considered, in general, to be better for welding the 0.040-in. steel. However, it must be remembered that good welds can be obtained with both projection diameters and that the precise value selected in this range is not critical.

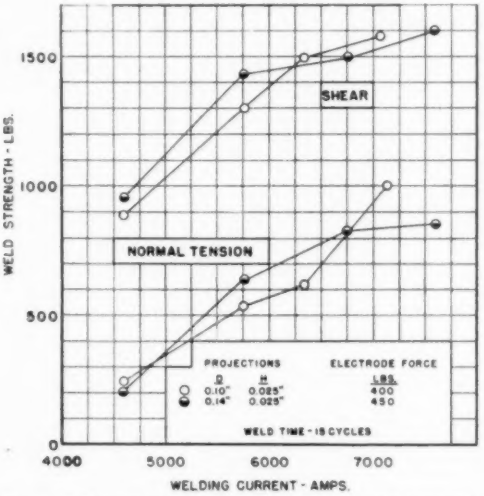

Fig. 4 Influence of projection diameter on weld strength, A.I.S.I. 1010, 0.040-in. steel

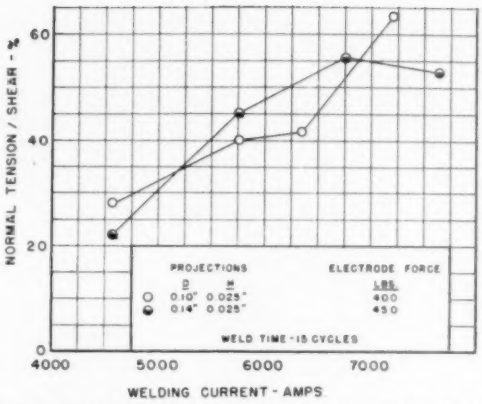

Fig. 5 Ratio of normal tension to shear strength for different diameter projections, A.I.S.I. 0.010, 0.040-in. steel

PROJECTION HEIGHT

Several different projection heights were investigated in each of the three different projection diameters. The effect of projection height on weld strength for the 0.10-in. diameter projection, can be seen in comparing Figs. 2 and 3. The weld strengths shown in Fig. 2 were obtained with a projection height of 0.011 in. whereas Fig. 3 shows similar data for a 0.025-in. height projection. In the latter case the electrode force was increased from 375 to 400 lb. to overcome the greater resistance of the higher projection to complete projection collapse. Maximum strengths are approximately equal for both projections but it may be seen that higher strengths can be obtained over a wider range of welding current for the higher projection. Furthermore, better consistency in strength was obtained for the welds made with the higher height. For these reasons the 0.025-in. projection height was chosen as being the most desirable.

In welding the 0.062- and 0.125-in. A.I.S.I. 1010 steel, it was found possible to obtain good weld strengths and plug-type failures in the normal tension test even though no fused zone was produced. This was achieved by using a projection with a height equal to about 25% of its diameter. The work done on the metal at the bond during projection collapse was sufficient to cause excellent adhesion by means of pressure welding. In order for satisfactory pressure welding to occur, that is, welding without actual melting of the metal, it is necessary to have a certain amount of plastic working of the metal. This working promotes grain growth across the interfaces resulting in a good bond without actual fusion. In welding projections of lower height in the same material, there was insufficient working of the metal to cause pressure welding. Hence adequate strength was not obtained with the low projection unless melting was present.

In the 0.040-in. material, projection collapse occurred so much easier than in either the 0.062- or 0.125-in. material that insufficient working of the metal was obtained to cause pressure welding. This was true for the high as well as the low projections. Consequently it was not possible to secure welds with appreciable strength unless a fused zone was produced, regardless of the projection height.

WELD DIAMETER

The strength of a projection weld is generally directly proportional to the size of the fused region. As just mentioned, it was not possible to obtain adequate strength without a fused zone in the 0.040-in. steel. It was further found that consistency in weld size and weld strength was reached only as the fused zone diameter was increased so that it was at least equal to the diameter of the projection. When using a 0.14-in. diameter projection, a weld fused zone of 0.17 in. proved to be very satisfactory. If the fused zones were increased much beyond this size, there was a tendency for them to become rather unsymmetrical both in shape and in relation to the location of the original projection. Excessively larger welds also expelled molten metal from between the sheets unless the electrode force was greatly increased. On the other hand, welds of insufficient diameter failed in the normal tension test by tearing through the weld; only the larger welds failed by pulling a plug out of one of the sheets. The plug type of failure is always desirable since it not only denotes good strength but also is generally associated with good consistency and dependability. A fused zone diameter of 0.17 in. was found to be the most satisfactory size for these reasons.

ELECTRODE FORCE

The electrode force was found to be a more important variable in projection welding than in spot welding. The electrode force must be sufficient to cause intimate contact of the projection and the opposing sheet during the whole welding process. Furthermore, it must be great enough to collapse completely the projection so that no sheet separation exists in the finished weld. If the electrode force is excessive, the projection will collapse too early in the welding period, before sufficient heat has been developed by the concentrated current. As a consequence, the resulting weld will be erratic and low in strength. It was found that better welds resulted if a slightly greater electrode force was used with the higher projections. For example, a 375-lb. electrode force proved satisfactory when employing a 0.10-in. diameter projection of 0.011-in. height, but this value was increased to 400 lb. for the 0.025-in. height projection in the same diameter. Since projection collapse is very easy to secure in the thin 0.040-in. steels, the choice of correct electrode force is not primarily determined by this consideration. Consistency, elimination of spitting at the initiation of the weld, the prevention of expulsion and the minimizing of porosity are more important factors to be regarded. For the 0.14 in.-diameter projection with a 0.025-in. height, an electrode force of 450 lb. was found to be the most satisfactory.

WELDING OF THE A.I.S.I. 1015 AND 1020 STEEL IN THE 0.040-IN. THICKNESS

The chief difference in welding behavior between the A.I.S.I. 1015 and 1020 steels and 1010 steel is the hardening effect of the slightly higher carbon content of these two steels. The same projection used in the lower carbon 1010 steel was found most satisfactory for the higher carbon steels. The same weld time, electrode force and welding currents were used, resulting in approximately the same size welds. A comparison of the normal tension and shear strengths of welds made with 0.10- and 0.14-in. diameter projections is shown in Fig. 6. The larger diameter projection did give somewhat better strength than the smaller one but the

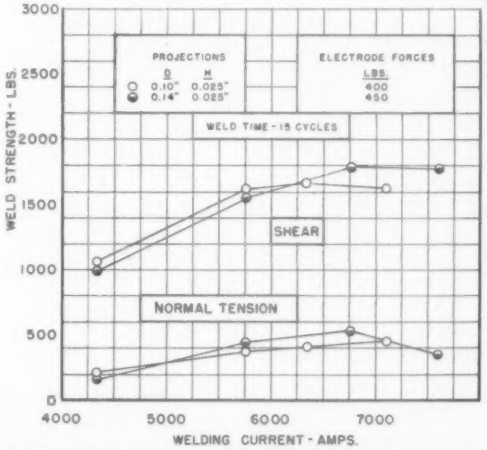

Fig. 6 Influence of projection diameter on weld strength, A.I.S.I. 1015, 0.040-in. steel

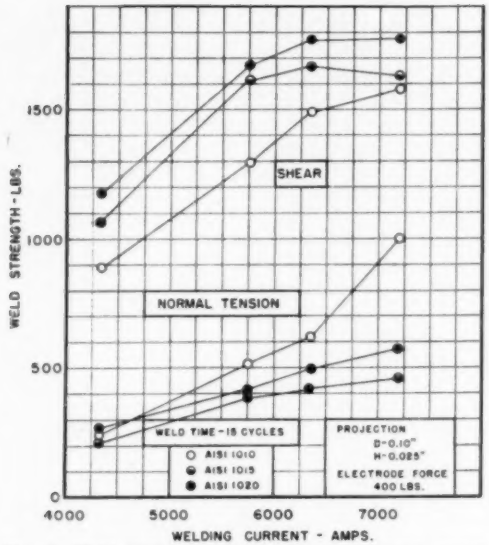

Fig. 7 Weld strengths for 0.040-in. low-carbon steels

influence of projection diameter in this range of diameters is seen to be not critical. This is similar to the results obtained for the 1010 and also the 1020 steels in the 0.040-in. thickness.

The normal tension and shear strengths for the three steels are plotted as a function of the welding current in Fig. 7. The shear strength of the welds in the 1015 and 1020 steels exceeded the shear strength of the welds in the 1010 steel, but the normal tension strength of welds in the two higher carbon steels was lower than that of the 1010 steel. The ratio of the normal tension strength to shear strength for the higher carbon steels was only about 60% of the values for the 1010 steel. This behavior is to be expected in comparing projection weld strength for two or more steels of differing hardness and hardenability. On cooling from the welding temperature, the weld and the surrounding steel which has been heated above the critical transformation temperature are hardened to a greater extent in the case of the higher carbon steels. This harder material is stronger but much less ductile than the somewhat softer A.I.S.I. 1010 welds. The shear strength is less affected by ductility and is more directly proportional to the strength of the base metal. Consequently, it is higher for the 1015 and 1020 steels. On the other hand, the normal tension strength of projection welds is critically sensitive to ductility and decreases in value for the higher carbon steels.

No plug type failures were obtained with welds in the 1015 or 1020 steels; all welds failed by a brittle tear through the fused zone parallel to the sheet interface.

RECOMMENDED CONDITIONS

The recommended conditions for the projection welding of 0.040 in A.I.S.I 1010, 1015 and 1020 steels are listed in Table 3. The normal tension and shear strength values obtained with these conditions are given in Table 4.

Table 3—Recommended Conditions for Welding A.I.S.I. 1010, 1015 and 1020 Steels in the 0.040-In. Thickness

Electrode force, lb.	450
Weld time, cycles	15
Welding current, amp.	5760
Projection:	
Diameter, in.	0.014
Height, in.	0.025
Approx. diameter of fused zone, in.	0.17

Table 4—Weld Strengths Obtained with the Recommended Welding Conditions

Material, A.I.S.I. No.	*Normal tension strength, lb.*	*Shear strength, lb.*	*Ratio of normal tension to shear strength*
1010	650	1430	45.4
1015	445	1560	28.5
1020	390	1580	24.7

MULTIPLE WELDS

Once conditions had been established for welding single projections, the welding of multiple weld specimens was investigated. In general, it was found that the correct values of electrode force and weld current were obtained by multiplying the previously established values for single projections by the number of projections.

(a) *0.040-In. Thickness*

Specimens were made using two, three and four projections simultaneously. Before making the final specimens to compare the multiple weld strength with single weld strength, the effect of projection spacing was studied. As had been previously noted in welding the thicker steels, the strength of a two-weld assembly increased as the distance between the projections was increased. This is shown clearly in Table 5.

Table 5—Double Weld Strength as a Function of Weld Spacing for 0.040.-In. Steel*

Spacing, in.	*Normal tension strength, lb.*	*Shear strength, lb.*
1/2	1080	2150
3/4	1285	2415
1	1300	2460

* Projection: $D = 0.10$ in.: $h = 0.025$ in. Material: A.I.S.I. 1010, 0.040 in.

It can be seen that both the normal tension and shear strengths increased appreciably when the distance between weld centers was increased from 1/2 to 3/4 in. There was some additional increase in strength when the spacing was increased from 3/4 to 1 in., but this change was much less. The multiple weld specimens in the 0.040-in. thickness were made with a 3/4-in. projection spacing. The strength of the single and

Table 6—Ratio of Single and Multiple Weld Strengths for 0.040-In. Steels

Steel	Double/Single		Three Welds/Single		Four Welds/Single	
	Normal tension	Shear	Normal tension	Shear	Normal tension	Shear
A.I.S.I. 1010	2.07	1.62	2.54	2.16	3.63	2.43
A.I.S.I. 1015	1.62	1.34	2.13	1.80	2.38	2.28
A.I.S.I. 1020	1.38	1.41	1.88	1.82	2.30	2.52

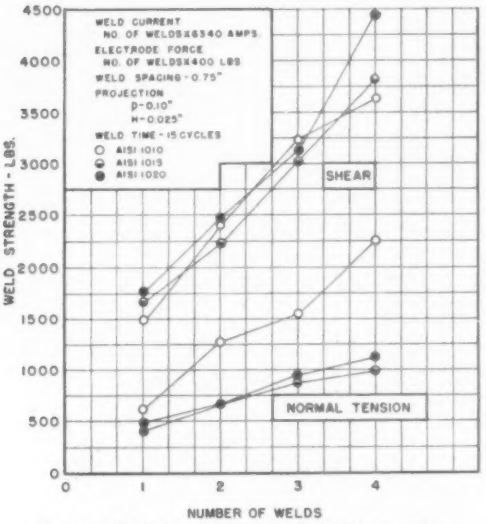

Fig. 8 Multiple weld strength for 0.040-in. steels

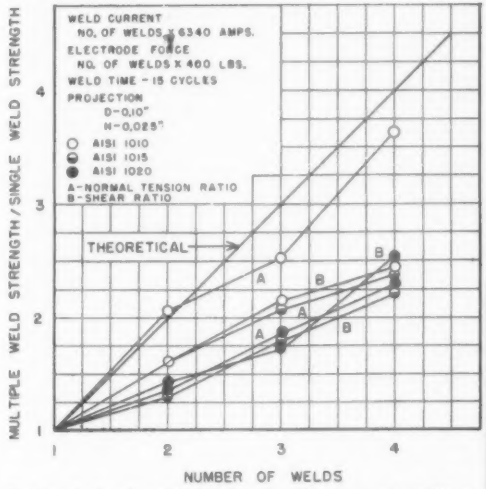

Fig. 9 Ratio of multiple to single weld strengths, 0.040-in. steels

multiple weld specimens for welds in 0.040-in. A.I.S.I. 1010, 1015 and 1020 are plotted in Fig. 8. The ratios of the multiple to single weld strengths are given in Table 6. These ratios are also plotted in Fig. 9 as a function of the number of welds. The ratio which would exist if each multiple weld specimen was equal in strength to the single weld strength multiplied by the number of welds, is plotted as the theoretical ratio. It can be seen from comparing these ratios that the ratios decrease as the carbon content of the steel was increased. The ratio for the normal tension strength for the steels in this thickness was higher than the ratio for the shear strength. The strength of the multiple weld was generally appreciably less than would be expected from calculations on the basis of single weld strength.

(*b*) *0.062- and 0.125-In. Thickness*

The multiple weld strengths and ratios of multiple to single weld strength values were less consistent than those for the 0.040-in. material. Correlation of the ratios for the different carbon contents and number of welds is more difficult. The weld strengths and ratios for the 0.062- and 0.125-in. thickness steel are listed in Tables 7 and 8.

Two-, three- and four-weld specimens were made for all the steels in the 0.062-in. thickness. The welds were spaced $^3/_4$ in. apart in all cases. In the double weld specimens, the projections were placed transversely to the specimen axis. In the three-weld specimens the welds were located at the corners of an equilateral triangle while the welds in the four-weld specimens formed a square with $^3/_4$-in. sides. The values of the

Table 7—Multiple Weld Strengths for 0.062-In. Steels

Material A.I.S.I. No.	Single Weld		Two Welds		Three Welds		Four Welds	
	Normal tension, lb.	Shear, lb.	Normal tension, lb.	Shear, lb.	Normal tension, lb.	Shear, lb.	Normal tension, lb.	Shear, lb.
1010	1010	2090	1545	3340	2100	4950	2480	6130
1015	475	2300	590	3340	770	4560	1230	5830
1020	425	2850	680	3960	810	5790	1780	7525

Ratio of Multiple Strength to Single Weld Strength

Material, A.I.S.I. No.	Two Welds		Three Welds		Four Welds	
	Normal tension	Shear	Normal tension	Shear	Normal tension	Shear
1010	1.53	1.60	2.08	2.37	2.46	2.96
1015	1.25	1.45	1.62	1.96	2.59	2.54
1020	1.60	1.39	1.90	2.03	4.19	2.68

* Projection: $D = 0.17$ in.; $h = 0.042$ in. Electrode force, lb. $= 750 \times$ no. of welds.

Table 8—Multiple Weld Strength for 0.125-In. Steels*

Material, A.I.S.I. No.	Single Weld—Normal tension, lb.	Single Weld—Shear, lb.	Two Welds—Normal tension, lb.	Two Welds—Shear, lb.	Three Welds, Normal tension, lb.
1010	4675	6060	6460	10,870	7950
1015	2100	8175	3120	12,630	5050
1020	2000	7825	3360	13,030	5000

Ratio of Multiple Strength to Single Weld Strength

Material, A.I.S.I. No.	Two Welds—Normal tension	Two Welds—Shear	Three Welds, Normal tension
1010	1.38	1.79	1.70
1015	1.49	1.54	2.41
1020	1.68	1.67	2.50

* Projection: $D = 0.30$ in.; $h = 0.055$ in. Electrode force, lb. = 2000 × no. of welds.

shear strength for these welds increased with the carbon content similarly to single projection welds. The ratio of multiple weld strength to single weld strength in general decreased with increasing carbon content. The main exception to this generalization is that of the 1015 steel which has slightly lower ratios than would be expected. The ratio of multiple to single weld strength was generally lower for normal tension than for shear tests.

In the 0.125-in. thickness, two- and three-weld specimens were made. Four-weld specimens failed in the plate and therefore gave no real indication of the strength of the welds. In the shear test even the three-weld specimen was strong enough to cause failure in the plate so the shear strength of the three-weld specimens is not listed. To get values for three- and four-weld specimens in both shear and normal tension it would be necessary to increase the test specimen width from the 2-in. width which was used throughout the investigation to a larger size.

EFFECT OF ELECTRODE MATERIAL

It was felt that the material of which the electrodes were made might have an appreciable effect on the size of the resulting weld. It was believed that I^2R heat developed in the electrodes might be an appreciable factor in the total heat of welding and that the resistance of the electrodes therefore should be considered in establishing correct welding conditions.

In order to investigate this effect, projection welds were made in 0.040-, 0.062- and 0.125-in. steel using electrodes of various resistance materials. The R.W.M.A. classification, and some of the properties of the electrode materials used are listed in Table 9.

Table 9—Electrode Materials

R.W.M.A. classification	Hardness, Rockwell B	Conductivity, % I.A.C.S.
Group B—class 12	100	27–21
Group A—class 3	95	50
Group A—class 2	80	80

The electrodes were $^3/_4$ in. in diameter in all cases. The projections and electrode forces used for the three different thickness of steel are listed below:

Thickness, in.	Projection—Diameter, in.	Projection—Height, in.	Electrode force, lb.
0.040	0.14	0.025	400
0.062	0.17	0.042	750
0.125	0.30	0.055	2000

The fused zone diameter as a function of the welding current is plotted in Fig. 10 for welds made in 0.040-in. steel using each of the three electrode materials. It is apparent from this figure that the electrode material influences the current requirements for making projection welds in the thickness steel. The greater the conductivity of the electrode material, the larger must be the current to make a given size weld. The lower resistance material develops less I^2R heat in the electrode. Since the size of the fused zone is determined by the amount of heat developed in the weld region minus the heat lost to the electrodes and surrounding sheet, the heat loss to the electrodes affects the weld diameter. The lower the temperature of the electrodes, the greater will be the heat loss to them and consequently the greater current needed for making a given size weld. The Group A, Class 2 electrodes, having the greatest conductivity (80% of I.A.C.S.), required the largest amount of current for a weld. The Group B, Class 12 electrodes, having the lowest conductivity (27–31% of I.A.C.S.), required the lowest current and the Group A, Class 3 electrodes, with a resistance between that of the other two materials, required intermediate currents.

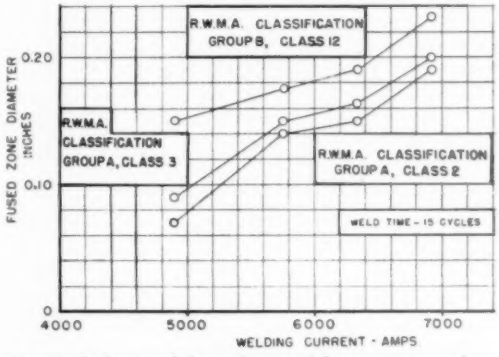

Fig. 10 Influence of electrode material on current requirements, 0.040-in. steel

In Fig. 11 the weld diameter as a function of the welding current is given for welds in 0.062-in. steel for each of the three electrode materials. A behavior similar to that just seen in the 0.040-in. steel was found also for the 0.062-in. steel. In this case also, the current required for making a given size weld increased with the conductivity of the electrode material. This in-

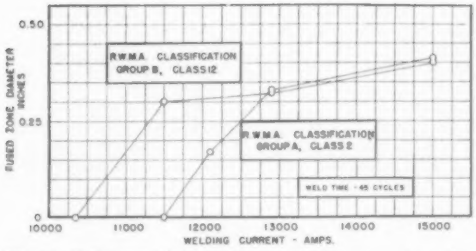

Fig. 11 Influence of electrode material on current requirements, 0.062-in. steel

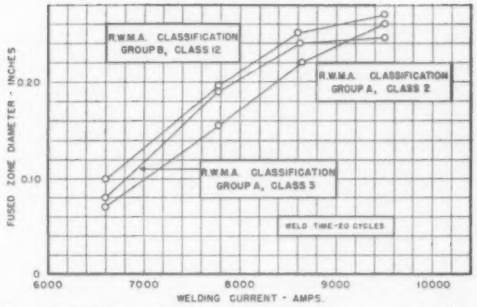

Fig. 12 Influence of electrode material on current requirements, 0.125-in. steel

crease, however, was not so great for the 0.062-in. thickness steel.

The same data is plotted in Fig. 12 for welds in 0.125-in. steel using only the lowest and highest conductivity electrode materials. A different relationship appears to exist for the welds in the thicker steel. At the lower weld currents, where there is little if any fusion, the electrode material has a definite effect. For example, using a weld current of 11,500 amp., a fused zone diameter of 0.30 in. was produced with the R.W.M.A. Group B, Class 12 electrodes whereas no fused zone at all was obtained under similar conditions with R.W.-M.A. Group A, Class 2 electrodes. Even though the current was raised to 12,100 amp. with the latter electrodes, a fused zone of only 0.17 in. resulted. At currents above 12,900 amp., the electrode material seemed to have little effect, the weld diameter being approximately the same for both electrodes.

In trying to explain why the effect of electrode material decreased with increasing plate thickness, it must be remembered that the same sized electrodes were used in making the welds in the three different thicknesses. Since the current was higher for welding the thicker steels, the I^2R heat developed in the electrodes would be greater. Consequently a higher electrode temperature would be produced in making welds in the thicker steel even though the same electrode material was used. This would mean a smaller proportion of the heat would flow to the electrodes and that a higher percentage would flow into the surrounding base metal. Since a smaller fraction of the total heat loss would be to the electrodes, the exact amount, determined by the electrode material, is of less influence. A more comprehensive investigation of the effect of electrode material would be necessary to investigate more thoroughly the quantitative effect of electrode diameter on current requirements.

A supplementary reason for the lack of dependence of the 0.125-in. steel on electrode material at weld diameters above 0.30-in., is that in this region the weld diameter does not vary rapidly with current changes. Since there is less reflection in the resulting weld diameter of minor changes in heat content, the effect of electrode material will not be very evident. At currents below this range, the weld diameter varies greatly with the current and the minor effect of electrode material on total heat content in the weld region will be reflected in differences in weld diameter.

CONCLUSIONS

1. Projections smaller in diameter than 0.010 in. are not satisfactory for welding 0.040-in. steels. Above this value, the exact diameter is not very critical, but a diameter of 0.14 in. proved most satisfactory.

2. Projections with heights approximately 20% of their diameter give greater consistency and better strengths over wider current ranges than lower projections.

3. Plug type failures in 0.040-in. A.I.S.I. 1010 steel could be obtained only with welds having a fused zone. No plug type failures were obtained for welds in 0.040-in. 1015 and 1020 steels.

4. When using the higher resistance electrode materials, less welding current is generally required to make a given size weld.

5. Multiple welds showed less strength per weld than did single welds. This decrease in expected weld strength was generally greater for the higher carbon steels.

ACKNOWLEDGMENT

The authors wish to express their appreciation to the Welding Research Council and the Resistance Welder Manufacturer's Association for sponsoring this investigation. They wish also to thank the Carnegie-Illinois Steel Corp. and the P. R. Mallory Co., for supplying steels and electrode materials used in the investigation.

Comparison of Notch Tests and Brittleness Criteria

The effect of fabrication processes on steels used in pressure vessels—Progress Report No. 1. A comparison of notch tests and notch-brittleness criteria

by C. J. Osborn, A. F. Scotchbrook, R. D. Stout and B. G. Johnston

FOREWORD

THE Fabrication Division of the Pressure Vessel Research Committee of the Welding Research Council has allocated to Lehigh University an extensive investigation designed to compare various steels as to their relative tendency toward brittle behavior at low temperature. Two steels, rimmed and aluminum-killed, each in two thicknesses ($^5/_8$ and $1^1/_4$ in.) have been selected for the over-all test program.

Particular emphasis in this program is being placed on the effect of fabrication processes involving plastic strain followed by heat, with or without welding, and subsequent strain aging. Since no standard test is generally accepted as a means to determine transition temperature it was necessary to select a test from the several in current use.

It is the purpose of this report to present the results of a comparison of different test methods on the basis of which the procedure to be used in the main program was determined. Later progress reports will present test results of the main investigation.

INTRODUCTION

The problem of brittle failure in welded steel storage vessels has many features in common with the failure of welded ships, about which a great deal has been published in recent months. The increasing tendency for a steel structure to fail in a brittle fashion as the temperature is lowered is known to depend on such factors as the stress distribution at the point of failure, geometrical constraints inherent in the design, the composition, melting and rolling history of the material and the forming, welding and heat-treatment practices employed during fabrication. The precise effects of these factors are individually uncertain and the problem is made more complex by the many variables involved. Through many parallel investigations there is a wide search for a satisfactory measure of this tendency to brittle failure.

Notched test specimens are commonly used to obtain a transition from shear to brittle, or cleavage, failure at temperatures in the region of atmospheric temperature, since it has been evident from service failures that this transition, under service conditions, may occur at temperatures at least as high as atmospheric. The notched specimen may be used in a tension, bend, tear or impact test and variations in each of these forms are currently in use. However, the notched bar impact tests have been criticized on the basis that the Charpy test fails to differentiate between steels which have distinctly different transition temperatures when tested in wide plate specimens. A variety of slowly loaded notched specimen tests have been suggested as improvements on the impact tests. Three of the most popular of these were selected for a thorough investigation to determine the most satisfactory means of following the transition from shear to brittle failure, as applied to the steels used in this particular investigation.

Initially it was thought that the Lehigh slow notched-bend test, developed earlier by the Metallurgy Dept.[1] at Lehigh, might not be as satisfactory as certain other tests, particularly in regard to the convenience and significance of the range of testing temperatures in which transition occurred.

For the purposes of the comparison, it was agreed beforehand that final selection of a test should be based on the following considerations:

(*a*) The results obtained should be reproducible and should show a well-defined transition from shear to cleavage failure in a suitable temperature range. This should apply to both types of brittleness criteria at present in use (see later).

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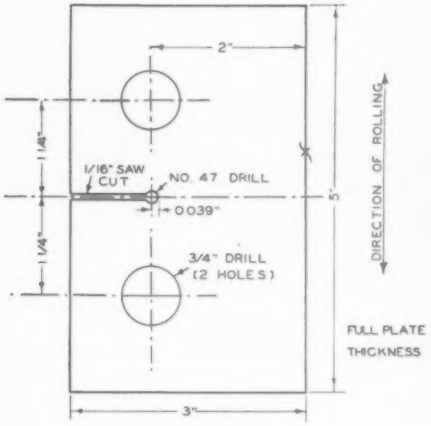

Fig. 1 (A) Specimen used in the Kahn tear test

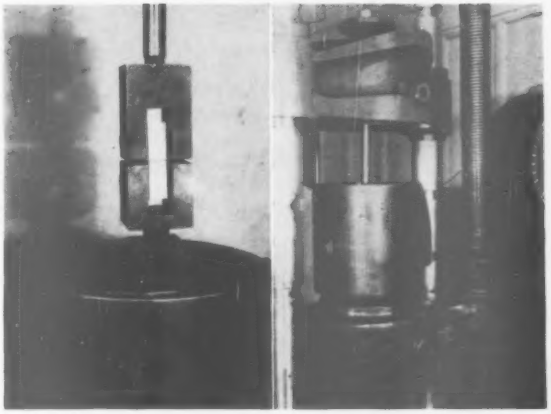

Fig. 1 (B) Kahn tear test

Showing method of holding specimen by pins and shackles

Fig. 1 (C) Kahn tear test

Showing method of loading and the constant - temperature bath. Note spherical bearing blocks to insure axial loading

(*b*) Convenience and cost of the test: test should be simple and rapid to perform; specimen should be economical of material and easily machined; testing rig should be of simple construction.

EXPERIMENTAL DETAILS

Description of Tests

The three tests chosen for comparison were the Kahn tear test, the Penn State slow notched-bend test and the Lehigh slow notched-bend test. These have been described in the literature previously but the following brief descriptions are given for completeness and to point out where modifications of the original specimens were made.

The Kahn tear test[2] is illustrated in Figs. 1 (*A*), (*B*) and (*C*). The specimen shown in Fig. 1 (*A*) is held by pins and shackles (Fig. 1 (*B*)) attached, through shafts mounted on spherical bearing blocks, to the heads of a standard testing machine, both specimen and shackles being surrounded by an insulated constant temperature bath as illustrated in Fig. 1 (*C*). The only significant modification of the procedure recommended by Kahn was made in testing the heavier ($1^1/_4$-in.) plate, when 1-in. pins were necessary to hold the specimens instead of the usual $^3/_4$-in. pins. The method of obtaining an autographic record of the load-deflection diagram was to magnify the relative displacement of the heads of the machine by a factor of 4, using a simple pulley and cord arrangement to obtain the magnification and to drive the recorder drum.

The Penn State test[3] is illustrated in Figs. 2 (*A*) and (*B*). This test was conducted exactly as it was developed at the Penn State laboratories. An autographic record of the load-deflection diagram was obtained by using a Kenyon-Burns-Young wedge-type extensometer, part of which can be seen in the upper left corner of Fig. 2 (*B*). The insulated tank which surrounds the testing jig and specimen during testing was removed for this photograph in order to show details of the jig.

The Lehigh slow notched-bend test[1] is shown in Fig. 3 (*A*) and (*B*). The specimen used was somewhat different to that developed as a weldability specimen, the differences being that the specimen in Fig. 3 (*A*) has a thickness of $^5/_8$ in. and uses an Izod notch of only 0.010-in. root radius, whereas the weldability specimen is the same thickness as the plate from which it is cut and the notch has a 0.040-in. root radius. In the case of the $1^1/_4$-in. plate, one side was machined to leave a $^5/_8$ in. thickness and the notches were in the rolled surface. The method of measuring bend angle by protractors clamped to each end of the specimen can be seen from Fig. 3 (*B*) and the simple cord and pulley arrangement for magnifying the relative motion of the crossheads on an autographic load-deflection diagram is partly visible behind the bending jig. In this test the specimen is transferred rapidly from a constant-temperature bath to the testing jig, where it is tested in air. In following this procedure, it is known that the change in temperature of the specimen due to gain or loss of heat to the atmosphere is negligible.

The crosshead speeds used in the three tests were as follows: Lehigh test, 3 in. per minute; Kahn test, 0.3 in. per minute; Penn State test, 0.1 in. per minute.

For all three tests, elevated testing temperatures were obtained by electrically heating oil or water; low testing temperatures were obtained by adding dry ice or liquid nitrogen to a medium of gasoline or alcohol. Specimens were always held at temperature long enough to ensure that they had reached the temperature of the bath before testing. Transition curves were established by testing four specimens at each of six temperatures.

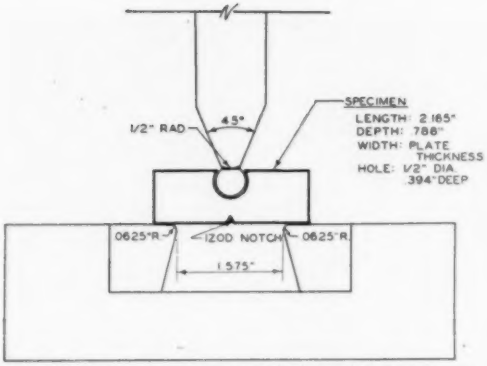

Fig. 2 (A) Penn State slow notched-bend test with compression zone of specimen replaced by hardened drill rod

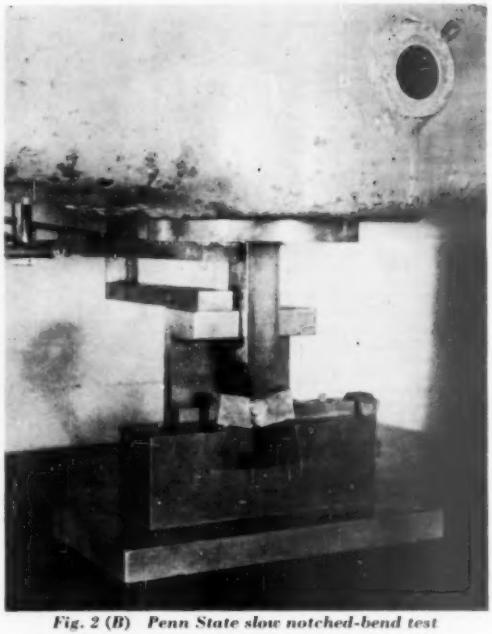

Fig. 2 (B) Penn State slow notched-bend test

Showing specimen partly broken. Kenyon-Burns-Young extensometer visible in upper left

Measurements Made on the Three Tests

It has recently been emphasized[4] that transition temperatures determined in different tests should only be compared when, in each test, the same criterion of brittleness is used to establish the transition curve. The transition curves for different tests are frequently constructed on the basis of quite different criteria. Thus, in the Penn State test, the appearance of the fracture and the per cent lateral contraction below the drilled hole have been used as criteria of brittleness; in the Kahn test, the appearance of the fracture and the energy absorbed by the specimen after passing the maximum load are the usual criteria; in the Charpy test, the total energy required to break the specimen is measured; in the Lehigh slow notched bend test, the bend angle at maximum load and the per cent lateral contraction below the notch have been used; Bagsar[5] used a tear test with the maximum load as criterion; Kinzel[6] recommended a bend test using per cent contraction below the notch as the criterion; and so on. However, it was evident in planning this comparison that the three tests could be compared only if all measurements commonly made on any one of the tests were made on all three. This necessitated the following measurements on each test:

1. Appearance of fracture: The percentage of the fracture area which exhibited a brittle or cleavage type of failure was measured on all specimens.

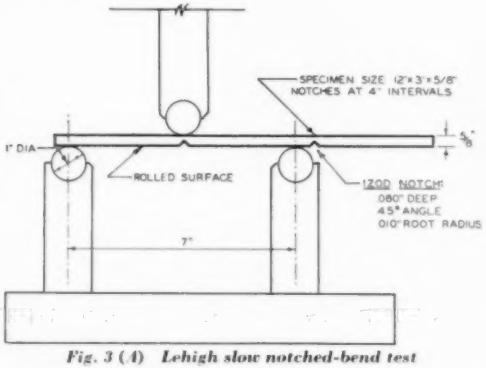

Fig. 3 (A) Lehigh slow notched-bend test

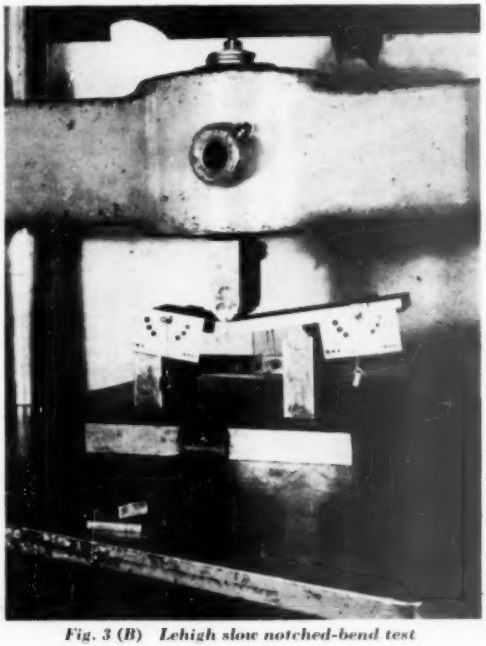

Fig. 3 (B) Lehigh slow notched-bend test

Showing test in progress

2. The energy absorbed by the specimen after passing the maximum load until the load had fallen to half the maximum: This was read from the autographic load-deflection curve up to the point of complete failure and an end-point for all specimens was therefore fixed at half the maximum load.

3. The percentage contraction in the width of the specimen at a point $^1/_{32}$ in. below the notch after fracture. A pointed micrometer was used for this purpose.

4. The percentage reduction in width at the mid-point of the specimen. In the Penn State specimen this was measured as the percentage contraction $^1/_{32}$ in. below the drill-hole.

5. Certain criteria of brittleness which could not be measured identically in all tests. The bend angle at maximum load in the Lehigh test was measured by attaching protractors to the specimen, a procedure which would have been impossible in the Penn State test. However, it was shown that the angle of bend was proportional to the displacement of the plunger in the Lehigh test, and this latter quantity, the bend deflection at maximum load, was read from the load-deflection diagram in the Penn State test.

In the Kahn tear test, the per cent elongation on a 2-in. gage length $^1/_4$ in. behind the notch was measured also.

Materials

The plates used in the comparison came from two heats of steel for which the complete mill history is known. One heat, aluminum-killed, had been supplied to A.S.T.M. Specification A-201 and the other, a rimming steel to A.S.T.M. Specification A-70. Both steels were tested in two plate thicknesses, $^5/_8$ and $1^1/_4$ in., and chemical analyses for the four plates are given in Table 1.

Table 1—Chemical Composition of Materials

	A-201		A-70	
	$^5/_8$ *in.*	$1^1/_4$ *in.*	$^5/_8$ *in.*	$1^1/_4$ *in.*
C	0.17	0.15	0.19	0.18
Mn	0.55	0.53	0.36	0.34
P	0.020	0.020	0.019	0.018
S	0.022	0.025	0.020	0.028
Si	0.21	0.19	0.02	0.02
Cu	0.06	0.08	0.13	0.15
Al	0.041	0.026	0.028	0.038
Al_2O_3	0.003	0.002	0.002	0.003
N_2	0.005	0.003	0.003	0.003
Ni	0.05	0.05	0.10	0.09
Cr	0.04	0.04	0.04	0.04
W	0.04	0.04	0.04	0.04
V	0.02	0.02	0.02	0.02
Mo	0.01	0.01	0.01	0.01

Each plate was tested in three conditions: (*a*) as-rolled; (*b*) after 10% plastic tensile strain; (*c*) after aging 2 hr. at 200° C. (392° F.) following the 10% tensile strain.

All cold-worked or strain-aged specimens were tested 7 days after the straining or heat-treatment operation.

RESULTS

Method of Plotting Results

All of the above-mentioned criteria of brittleness may be plotted against temperature. However, because of the considerable scatter obtained in the results of this type of work, there has been much controversy regarding the method of drawing a curve to represent the results.[3, 7] The authors consider that there is little justification for the common procedure of drawing the "best-fitting" smooth curve through a mass of scattered data, and they have chosen simply to join the mean values for each temperature by straight lines.* This method has the important advantage that it is completely independent of any personal element.

Definition of Transition Temperature

The method of defining transition temperature has been the subject of just as much controversy as has the type of curve to be drawn. In this report the transition temperature is defined as the temperature at which the curve, drawn as described in the previous section, has a value equal to the arithmetic mean of its maximum and minimum values. Thus, if the criterion under consideration is the per cent cleavage in the fracture surface, the transition temperature is the temperature at which the curve has a value of 50% cleavage.

Recent moves to define the transition temperature, on the basis of fracture appearance, as the highest temperature at which one specimen out of four or five shows more than 50% cleavage, are equivalent to choosing the temperature at which the curve described above has a value of approximately 80% cleavage. There appears to be no valid reason for choosing such a point in preference to the 50% point, which has the following distinct advantages:

(1) The temperature is known to be in the middle of the scatter zone, whereas the most that can be said

* Where, in a very few cases, this method would produce a change in sign of the slope between two adjacent testing temperatures within the transition or scatter zone, the points at each end of this inconsistent section were bypassed and the straight lines drawn to the mid-point of the section.

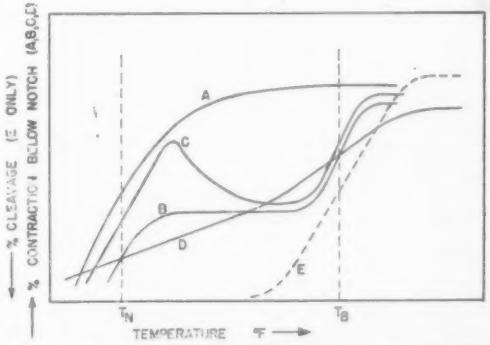

Fig. 4 Diagram showing types of transition curves obtained on notched specimens

Using per cent contraction below the notch in A, B, C and D; per cent cleavage in E

for an 80% point is that it is probably near the upper limit of the scatter zone.

(2) The slope of the transition curve is a maximum at this point and the temperature is therefore fixed with greater accuracy than at other points on the curve.

The above definition applies in a straight-forward manner to all per cent cleavage curves as shown for Curve *E* in Fig. 4 and also to per cent contraction-below-the-notch curves of type *A* in Fig. 4. However, some curves, such as *B* and *C* in Fig. 4, show two definite stages in the transition and for these curves two transition temperatures are defined according to the definition given earlier. It was found experimentally and is shown in Fig. 4 that transition temperatures defined in this way occur at two distinct temperatures for one steel. The temperature determined by Curve *A* and the lower sections of *B* and *C* will be called T_N and the higher temperature determined by Curve *E* and the upper sections of *B* and *C* will be called T_B. The significance of T_N and T_B will be discussed in detail later. Curve *D* gives evidence of both T_B and T_N but does not have the two sudden transitions of Curve *B*.

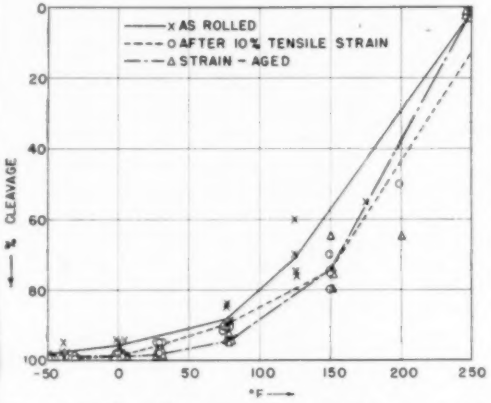

Fig. 5 (A) Transition curves for A-70 1¼-in. material
Lehigh bend test. Criterion: per cent cleavage

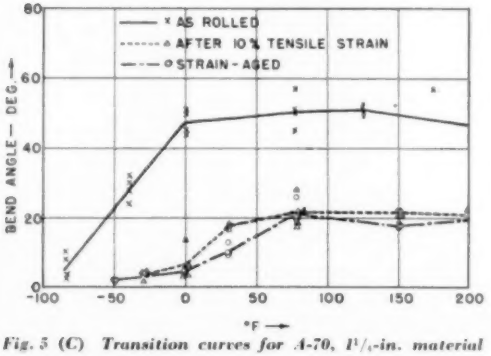

Fig. 5 (C) Transition curves for A-70, 1¼-in. material
Lehigh bend test. Criterion: bend angle

In the energy vs. temperature plots of the Lehigh bend results, some of the curves lacked points at temperatures sufficiently high to ensure that a maximum energy value had been reached; in this case, therefore, the transition temperature was taken as that giving a prescribed energy level (312.5 ft.-lb.)

Experimental Results

A complete set of transition curves for the A-70, 1¼-in. material is given in Figs. 5, 6 and 7. The other three materials showed essentially the same types of curves. Experimental results for all materials are summarized as transition temperatures in Tables 2, 3 and 4.

Since transition temperatures of one material according to different criteria applied to the same type of test may be as much as 200° F. apart, it was necessary to test over a wide temperature range with the limited number of specimens available. Testing temperatures were therefore more widely spaced than is usual when only one criterion is being investigated, but it is never-

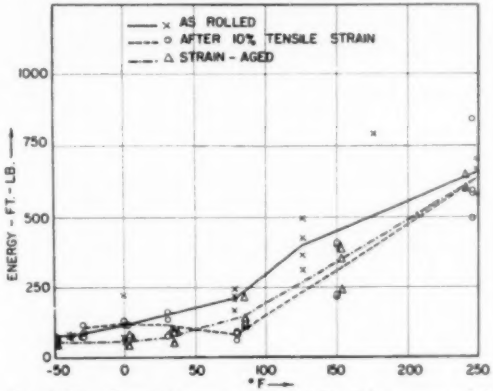

Fig. 5 (B) Transition curves for A-70, 1¼-in. material
Lehigh bend test. Criterion: energy after maximum load

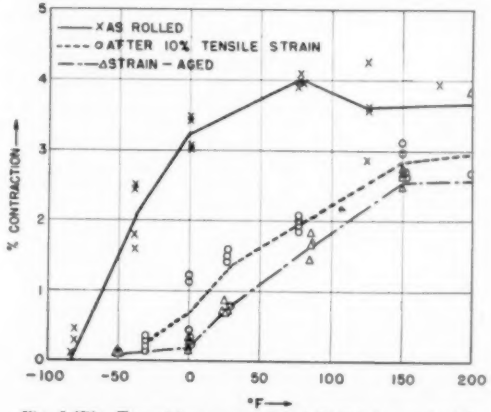

Fig. 5 (D) Transition curves for A-70 1¼-in. material
Lehigh bend test. Criterion: percent contraction below notch

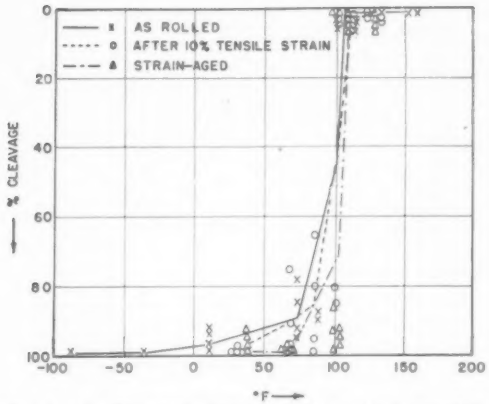

Fig. 6 (A) Transition curves for A-70, 1¼-in. material
Penn State test. Criterion: per cent cleavage

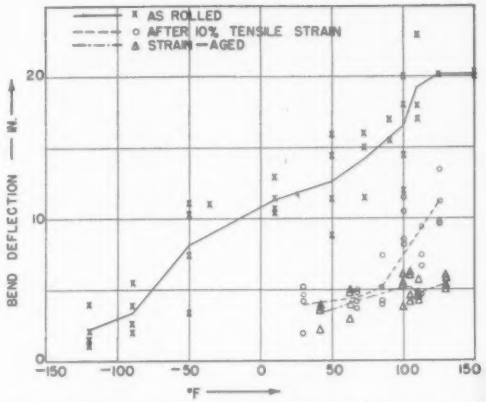

Fig. 6 (D) Transition curves for A-70, 1¼-in. material
Penn State test. Criterion: bend deflection

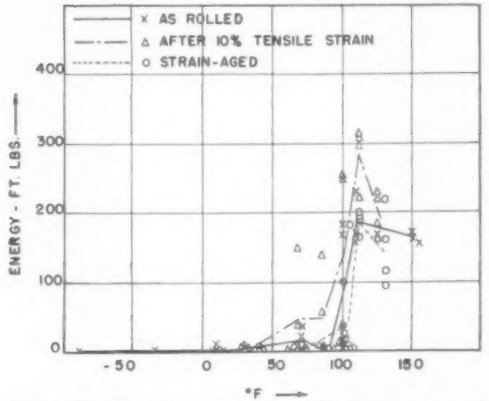

Fig. 6 (B) Transition curves for A-70, 1¼-in. material
Penn State test. Criterion: energy after maximum load

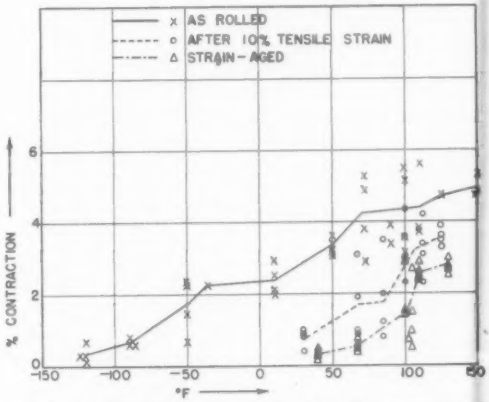

Fig. 6 (E) Transition curve for A-70, 1¼-in. material
Penn State test. Criterion: per cent contraction below notch

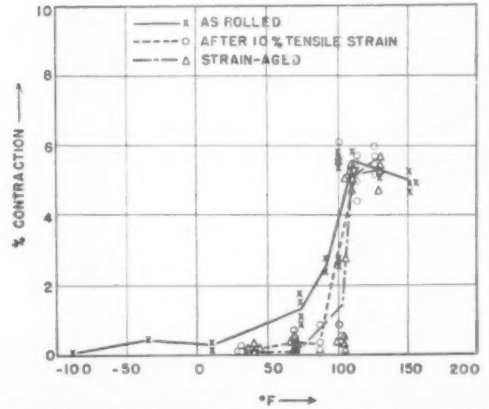

Fig. 6 (C) Transition curves for A-70, 1¼-in. material
Penn State test. Criterion: per cent contraction below drill-hole

Table 2—Transition Temperatures in °F., Lehigh Slow Notched-Bend Test

	% Brittle T_B	*Energy* T_B	*Bend angle* T_B	*% Contraction below notch* T_N
A-201, ⅝ In.				
As-rolled	41	33	−88	−68
Strained	45	43	−72	−44
Strain-aged	101	95	−13	30
A-201, 1¼ In.				
As-rolled	95	77	−78	−58
Strained	123	95	−17	0
Strain-aged	156	105	−21	32
A-70, ⅝ In.				
As-rolled	100	85	−74	−76
Strained	123	143	5	37
Strain-aged	177	197	−22	15
A-70, 1¼ In.				
As-rolled	162	103	−46	−42
Strained	190	152	12	45
Strain-aged	183	138	30	60

Table 3—Transition Temperatures in ° F., Penn State Slow Notched-Bend Test

	% Brittle T_B	Energy T_B	% Contraction at drill-hole T_B	Bend Deflection T_B	Bend Deflection T_N	% Contraction at notch T_B	% Contraction at notch T_N
A-201, 5/8 In.							
As-rolled	−23	−15	−11	−32	−100	−9	−100
Strained	−19	−26	−13	−30	..	−22	..
Strain-aged	−8	−13	−5	−7?	..	−13	..
A-201, 1 1/4 In.							
As-rolled	43	43	43	41	−100	39	−60
Strained	22	21	26	18	..	14	..
Strain-aged	43	40	47	27	..	27	..
A-70, 5/8 In.							
As-rolled	38	41	42	34	−90	48	−90
Strained	16	17	16	7	..	7	..
Strain-aged	53	55	58	53	..	60	..
A-70, 1 1/4 In.							
As-rolled	97	98	92	89	−70	53	−70
Strained	98	101	99	100	..	94	..
Strain-aged	106	108	105	..	..	103	..

theless believed that most of the transition temperatures quoted in Tables 2, 3 and 4 are accurate to within ±10° F. Additional tests were made for almost all "as-rolled" curves in order to check certain ideas suggested by the original 24 specimens; this accounts for the larger number of points on the "as-rolled" curves in Figs. 5, 6 and 7.

It should be mentioned that autographic load-deflection curves on these tests can only be obtained by using the movement of the heads of the testing machine as a measure of the deformation in the specimen. Particularly in the Penn State and Kahn tests, using high loads and small deflections, the measurement of the energy absorbed after passing the maximum load therefore involves inaccuracies due to elastic deflection in the head of the machine. Also, in all three specimens appreciable deformation occurs in regions removed from the notch, but the energy associated with this deformation is absorbed prior to the maximum load and does not affect the measurement of energy after maximum load.

DISCUSSION OF RESULTS

Comparison of Criteria

The results in Table 2 and Fig. 5 show very clearly that the Lehigh bend test divides the brittleness criteria into two distinct groups: Group I, comprising the fracture appearance and the energy after maximum load, giving transition temperatures between 100 and 200° F. higher than Group II, which consists of the bend angle at maximum load and the per cent contraction below the notch. Group I criteria have a transition curve as in Type *E* of Fig. 4. The agreement between transition temperature according to different criteria in the same group is generally good.

In the Penn State test and Kahn tear test similar groups of criteria may be distinguished except that Group II criteria here show curves of types *B*, *C* and *D* in Fig. 4, instead of Type *A*. Curve *B* may be regarded as an ideal curve from which experimental curves frequently deviate toward either *C* or *D*. Group I criteria invariably show the simple Type *E* curve. (See Figs. 5 (*A*), 6 (*A*) and 7 (*A*).)

Now, although the actual temperatures vary from test to test, each of the three tests does distinguish two different transition temperatures, one (T_B) some 100–200° F. higher than the other (T_N). Group I criteria may be defined as those which show *only* the high temperature transition at T_B, while Group II criteria are those which are influenced by the transition at T_N. The latter (T_N) is clearly shown in the Lehigh bend test

Table 4—Transition Temperatures in ° F., Kahn Tear Test

	% Brittle T_B	Energy T_B	% Contraction at Midpoint T_B	% Contraction below Notch T_B	% Contraction below Notch T_N	Elongation T_B	Elongation T_N
A-201, 5/8 In.							
As-rolled	28	14	20	..	−120	..	..
Strained	60	32	55	..	..	..	..
Strain-aged	73	..	65	..	−60	..	..
A-201, 1 1/4 In.							
As-rolled	87	57	87	50	−100	50	−120
Strained	102	93	100	86	..	90	..
Strain-aged	140	140	138	141	..	140	..
A-70, 5/8 In.							
As-rolled	60	60	58	57	−110	62	−100
Strained	88	85	85	85	..	85	..
Strain-aged	103	83	95	105	..	110	..
A-70, 1 1/4 In.							
As-rolled	145	156	125	134	−35	142	−45
Strained	192	196	182	175	..	175	..
Strain-aged	200	205	188	168	..	170	..

and its existence is demonstrated in both the Penn State and Kahn tests, although here Group II criteria also show evidence of the upper transition (T_B). Consideration may now be turned to the significance of the two temperatures T_B and T_N.

Two important observations may be made on this subject:

(1) In terms of the load-deflection diagram obtained during testing, Group I criteria are measures of the energy absorbed after passing the maximum load, while Group II criteria are either measures of the energy absorbed by the specimen up to the maximum load or are very strongly influenced thereby.

(2) T_B clearly corresponds to the transition in the fracture appearance (curve E in Fig. 4), but at temperatures far below T_B a small zone immediately below the notch continues to fail in a ductile manner. It was verified, for each of the three tests investigated, that

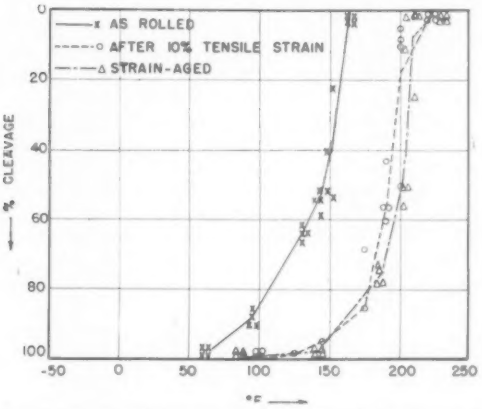

Fig. 7 (A) Transition curves for A-70, 1¼-in. material
Kahn tear test. Criterion: per cent cleavage

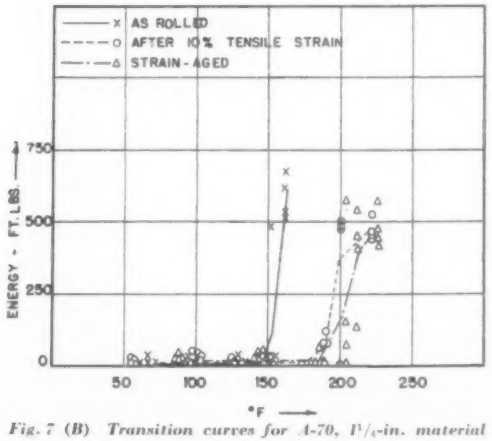

Fig. 7 (B) Transition curves for A-70, 1¼-in. material
Kahn tear test. Criterion: energy after maximum load

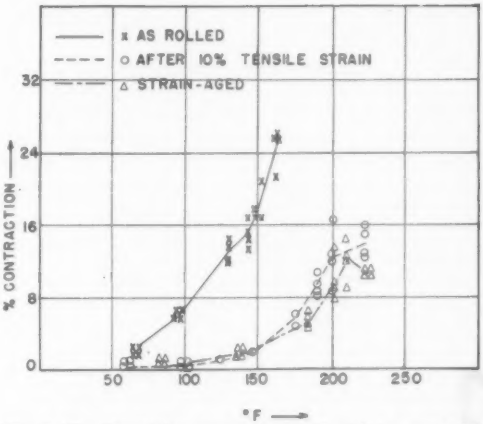

Fig. 7 (C) Transition curves for A-70, 1¼-in. material
Kahn tear test. Criterion: per cent contraction at mid-point

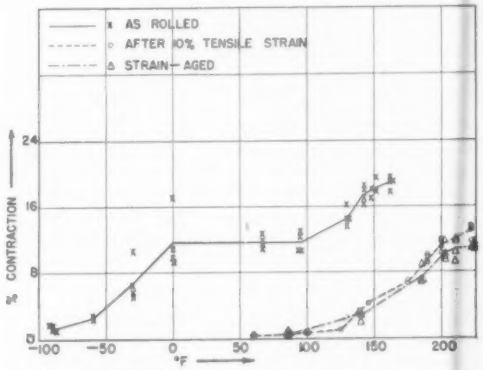

Fig. 7 (D) Transition curves for A-70, 1¼-in. material
Kahn tear test. Criterion: per cent contraction below notch

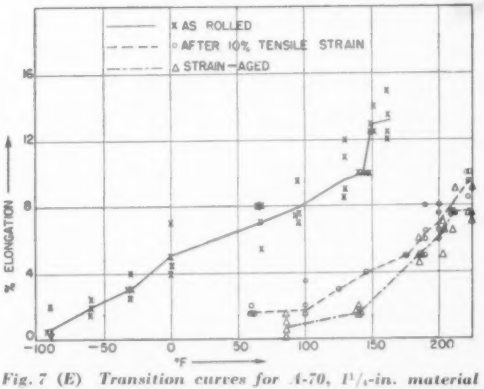

Fig. 7 (E) Transition curves for A-70, 1¼-in. material
Kahn tear test. Criterion: per cent elongation ¼ in. below notch

T_N corresponds to the transition in fracture appearance in this small zone below the notch.

Thus, T_N may logically be considered as the temperature of transition from a shear to cleavage mode of fracture under the stress conditions imposed by the notch machined in the specimen surface, while T_B is a similar transition temperature for the stress conditions existing at the base of a sharp crack formed by shear fracture immediately below the notch. The fundamental effects of geometry and stress conditions on transition temperatures have been discussed very fully in the literature[5, 9] and it would be expected from the known principles that T_B, the transition temperature for the sharper effective notch, would be appreciably higher than T_N. The magnitude of this effect may be gaged from the fact that, using the $^5/_8$-in. Lehigh bend specimen on A-70, $1^1/_4$-in. plate, T_N for a notch of 0.010 in. radius was found to be about 80° F. higher than for a notch of 0.040 in. radius. Stout and McGeady[4] have recently published results of investigations in which T_N varied by as much as 100° F. between notches of different severity.

Moreover, since T_B is higher than T_N, the transition at temperature T_B occurs in metal which has been plastically deformed prior to and concurrently with initial shear fracture at the root of the notch. The temperature T_B is therefore a characteristic of deformed metal and not of the metal before it is tested. Table 2 shows that a 10% plastic strain may raise T_N by as much as 100° F., so that this effect, together with that of the different effective notch severities, can readily account for differences between the temperatures T_B and T_N of the order of magnitude encountered in Tables 2, 3 and 4.

The practical implications of this discussion of the two transition temperatures are very important. The temperature T_B, which is determined when fracture appearance, energy after maximum load, etc., are employed as the brittleness criterion, is the transition temperature of the material after a severe but indeterminate cold deformation. The stress system producing the transition is that obtaining at the base of a crack.

On the other hand, the temperature T_N influences only those criteria which fall in the Group II defined above, and is the transition temperature of the material under the stress system prevailing at the base of a machined notch. It should be pointed out that the root radius of the machined notch changes during a test and the radius at failure is different in different steels. However, Group II criteria possess the important property of being sensitive to notch acuity and other surface or near-surface effects to which T_B and the Group I criteria are completely insensitive. In some cases, such as the Lehigh Weldability Test, welding effects may be regarded as surface or near surface phenomena having little or no effect on T_B and Group I criteria.

Comparison of Tests

The original object of this investigation was to compare the three tests on the basis of the considerations outlined above (see Introduction). The following conclusions were reached as a result of the experience gained in performing the large number of tests reported herein:

(*a*) *Results.* (1) Transition Temperatures: As can be seen from Tables 2, 3 and 4, there was little to choose between the tests with respect to the temperature ranges in which the transitions occurred.

(2) Effect of Criterion: The Lehigh test was the only one to determine T_N satisfactorily. T_B could be determined equally well by all three tests, although the transition zone was wider in the Lehigh test than in the other two.

(3) Reliability: The Penn State results conflicted with those of the other tests and were inconsistent within themselves, in that the $1^1/_4$-in. A-201 and $^5/_8$-in. A-70 plates showed transition temperatures after straining, and sometimes even after strain-aging, which were lower than those of the as-rolled materials.

(*b*) *Convenience and Cost of the Test.* (1) Machining: There was little to choose between the three tests in the matter of machining time but the Lehigh and Kahn tests probably had an advantage over the Penn State test.

(2) Testing Rig: The Lehigh test setup was the simplest of the three, but both the bend tests were much simpler than the Kahn test. The latter was the only one in which regular replacements of any parts, in this case the pins, were necessary.

(3) Ease and Speed of Testing: Here again the bend tests were definitely superior to the Kahn test, with the Lehigh test somewhat quicker and more convenient than the Penn State test.

(4) Size of Specimen: The Penn State test was considerably more economical of material than the Kahn and Lehigh tests, the latter using slightly more than the Kahn.

It was decided on the basis of these findings to adopt the Lehigh slow notched-bend test for future work requiring transition curve determinations. The fact that the Lehigh notch is in the surface is apparently unimportant, even with the A-70 steel, as the Lehigh results conform quite well to the pattern of the Kahn test results.

Values of T_B determined by the Lehigh test were generally slightly higher than those determined by the Kahn test, these in turn being some 50° F. or so higher than those of the Penn State test. It seems probable that these differences in T_B can be explained on the basis of specimen geometry, the greater restraint due to the greater width of the Lehigh specimen and the greater notch depth of the Kahn tear specimen being responsible for the higher values of T_B in these tests. However, there are two factors to complicate this simple picture; firstly, the speed of testing is different in each test; secondly, the amount of cold-work preceding failure is probably different in the three tests.

The values obtained for T_N were not very reliable in the Kahn and Penn State tests but generally speaking they were both lower than the T_N value given by the

Lehigh test. This, also, is probably due chiefly to differences in geometry.

Effect of Materials

The effect of cold work and strain-aging on the transition temperatures of A-70 and A-201 steels is to be the subject of a future paper but some conclusions may be drawn from the results presented in Tables 2, 3 and 4.

In all tests T_B was considerably higher for the rimming steel than for the aluminum-killed steel as-rolled. In the Lehigh and Penn State tests the difference was very close to 60° F.; in the Kahn test it varied from 30 to 50° F. Except for the inconsistencies in the Penn State results mentioned above, T_B generally increased after cold-work and increased further after strain aging. The increase in T_B due to strain aging was approximately the same in both steels.

The effects on T_N may be judged only from the results of the Lehigh test in Table 2. It appears from these, however, that T_N may not be as susceptible to differences in deoxidation practice as is T_B, but that it is very sensitive to strain-aging effects.

Two chemical factors have been suggested recently as governing the value of T_B; they are the nitrogen content[10] and the Mn:C ratio.[11] It is interesting to note that although the two steels investigated had approximately the same nitrogen content, T_B for the rimming steel was 60° F. higher than for the aluminum-killed steel. The authors consider that nitrogen content is of more significance in strain-aging phenomena than in the consideration of transition temperatures, and in this connection it is of interest to recall that the effect of strain-aging on T_B and T_N was much the same in both steels.

From Table 1 it can be seen that the two steels have Mn:C ratios of almost 2 for the A-70 steel and about 3½ for the A-201 steel. According to Barr and Honeyman,[11] the higher Mn:C ratio should correspond to a lower value of T_B and it is believed that the higher Mn:C ratio of the A-201 steel contributed to its lower transition temperatures.

Effect of Plate Thickness

In all tests, T_B for the 1¼-in. material was about 60° F. higher than for the corresponding ⅝-in. material. In the Penn State and Kahn tests this may have been partly a result of geometrical differences but since the Lehigh specimens, which were machined to the same geometry, showed the same effect there was clearly a difference in the materials being tested.

Using the Lehigh slow notched-bend test, transition curves were determined on ⅝-in. thick specimens normalized 1 hr. at 1600° F. before notching for both steels in both thicknesses. The results are summarized in Table 5. It is evident that while some difference remained between transition temperatures corresponding to parent plates of different thickness, this difference was largely removed by the normalizing treatment. This suggests that such differences were largely the result of the different cooling rates experienced by plates of different thickness in cooling from the finishing temperature after rolling.

Table 5—Transition Temperatures for Normalized Materials

	T_B, ° F.	T_N, ° F.
A-201, ⅝ in.	−55	−110
A-201, 1¼ in.	−25	−115
A-70, ⅝ in.	51	−91
A-70, 1¼ in.	40	−85

CONCLUSIONS

1. Each of the three notch tests investigated could be used to determine two types of transition temperature depending on the brittleness criterion used.

2. The upper temperature, T_B, is that determined by a group of criteria of which the fracture appearance is usually the most satisfactory; it is the transition temperature of the material after considerable cold-work and under the stress conditions pertaining at the base of a sharp crack.

3. The lower temperature, T_N, from 100 to 200° F. lower than T_B, is best determined by using the per cent lateral contraction below the notch as the criterion of brittleness; it corresponds to the transition temperature of the undeformed material under the stress system imposed by the machined notch.

4. Of the three notch sensitivity tests examined, the Lehigh slow notched-bend test was considered the most satisfactory.

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Impact Tests of Pressure Vessels at −320° F.

Tests of welded pressure vessels of 8½% nickel steel under shock loading at the temperature of liquid nitrogen and comparison with carbon and stainless steel vessels

by T. N. Armstrong

IT IS generally established practice in comparing materials of construction to classify such materials on the basis of mechanical properties determined by laboratory tests, but before a material is widely applied in engineering structures it is desirable, and certainly reassuring to the designer and the ultimate user, to be able to refer to successful experience with similar structures of the same material, operating under comparable conditions of stress and environment. Obviously, any new material is subjected rather critical scrutiny as it has no history of operating performance. To bridge this gap, tests frequently are made on model or pilot structures, imposing conditions that are equally or more severe than anticipated in actual service.

The high mechanical properties of 8½% nickel steel created considerable interest among users of pressure vessels that are required to operate at liquid air temperatures and although laboratory tests at −320°F. on welded and unwelded specimens indicated a considerable degree of toughness at the temperature of liquid nitrogen,[1, 2] there was some hesitancy in applying the material for commercial installations, even though the economics were favorable.

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In order to determine how welded pressure vessels of 8½% nickel steel would behave under shock loading at very low temperatures, several small vessels were constructed and subjected to impact when filled with liquid nitrogen. A carbon steel vessel and a stainless steel vessel also were included in the test.

DESIGN OF VESSELS

Except for differences in materials and in heat treatment, design details, Fig. 1, for all vessels were the same. This particular design was selected as it incorporated most of the features associated with full size commercial vessels. The vessels were approximately 42 in. long by 12 in. in diameter with ¼-in. wall.

MATERIALS

All materials were from commercial melts. The carbon steel wrapper sheets and heads were specified to meet requirements of A.S.T.M. Specifications A201, but it will be noted that neither the chemical nor the physical requirements were met in either the heads or the wrapper sheet. This discrepancy was not detected until after the vessels had been tested, but it is believed that it had little bearing on the results of the low temperature tests.

Analyses of the steels were as follows:

Table 1—Chemical Analysis, Samples Taken from Vessels After Test

Type steel	*% C*	*% Mn*	*% Si*	*% P*	*% S*	*% Ni*	*% Cr*
Carbon, heads	0.16	1.22	0.24	...	...	...	...
Carbon, wrapper sheet	0.21	0.31	0.01	...	...	...	...
8½% nickel (AISI 2800)	0.10	0.74	0.27	0.010	0.023	8.69	...
Stainless (AISI 304)	0.09	1.35	0.50	0.025	0.020	9.03	18.67

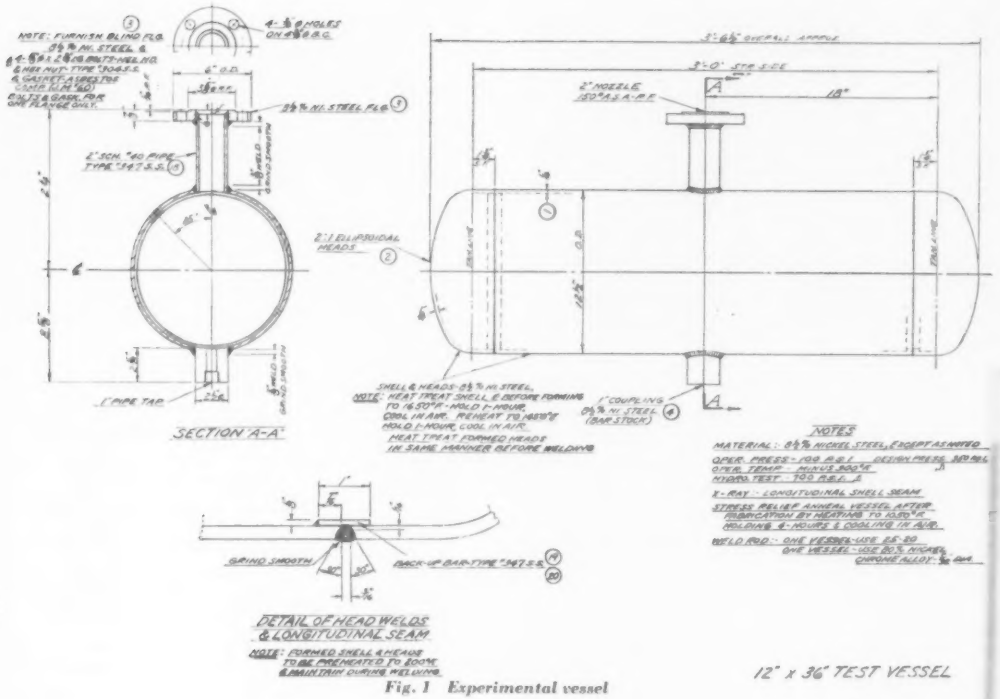
SECTION A-A
2:1 ELLIPSOIDAL HEADS
SHELL & HEADS-9% Ni STEEL
NOTE: HEAT TREAT SHELL & HEADS BEFORE FORMING TO 1650°F. HOLD 1 HOUR. COOL IN AIR. REHEAT TO 1480°F HOLD 1 HOUR. COOL IN AIR. HEAT TREAT FORMED HEADS IN SAME MANNER BEFORE WELDING
COUPLINGS 9% Ni STEEL (BAR STOCK)
NOTES
MATERIAL: 9% NICKEL STEEL, EXCEPT AS NOTED
OPER. PRESS.- 100 P.S.I. DESIGN PRESS. 500 P.S.I.
OPER. TEMP. MINUS 300°F
HYDRO TEST 750 P.S.I. ✓
X-RAY: LONGITUDINAL SHELL SEAM
STRESS RELIEF ANNEAL VESSEL AFTER FABRICATION BY HEATING TO 1050°F. HOLDING 4 HOURS & COOLING IN AIR.
WELD ROD: ONE VESSEL-USE 25-20
ONE VESSEL-USE 80% NICKEL CHROMEALLOY
DETAIL OF HEAD WELDS & LONGITUDINAL SEAM
NOTE: FORMED SHELL & HEADS TO BE PREHEATED TO 300°F. & MAINTAIN DURING WELDING
12" x 36" TEST VESSEL

Fig. 1 *Experimental vessel*

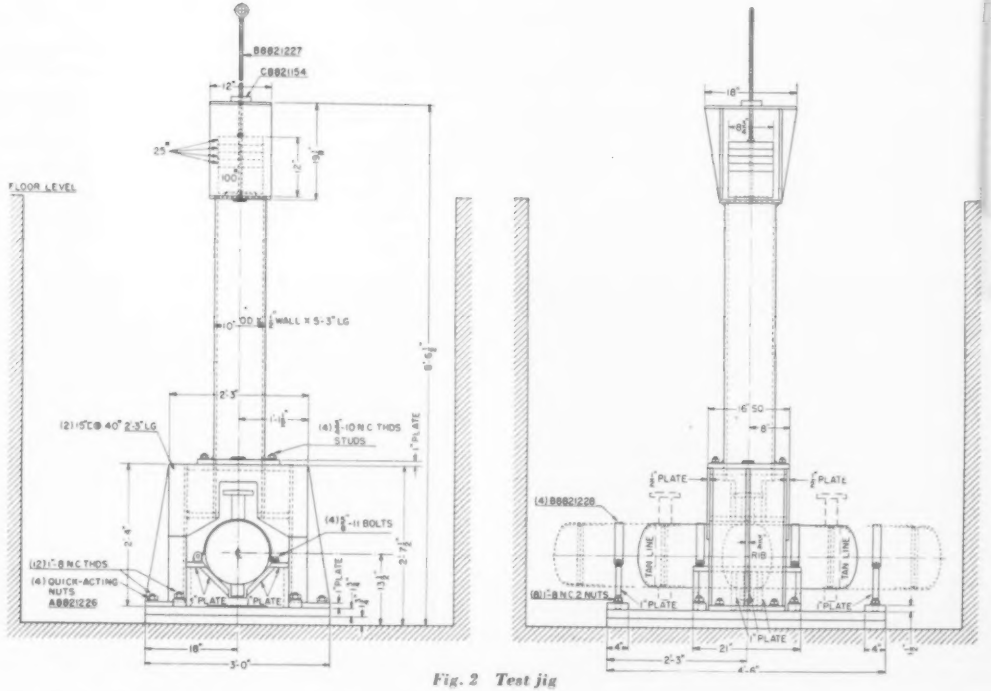

Fig. 2 *Test jig*

Representative tensile properties of the three steels, based on tests of cylindrical 0.505-in. specimens are as follows:

Type steel	*Yield strength, psi.*	*Tensile strength, psi.*	*Elongation in 2 in., %*
Carbon (A201)	37,200	62,300	31.5
8½% Nickel	92,000	110,000	28.0
Stainless	35,000	85,000	55.0

Heads were hot formed, and heads and plates were heat treated as follows before fabrication: Carbon steel, normalized 1650° F.; 8½% nickel steel, double normalized from 1650 and 1450° F.; stainless steel, annealed (quenched) from 1800° F.

FABRICATION

Details of design are shown in Fig. 1. Backing strips were used for the longitudinal seam and one circumferential seam but not for the closing circumferential weld. The following vessels were constructed for test:

Type of material	*Backing strip*	*Weld rod*	*Stress relief*
Carbon steel	Carbon steel	E6015	1100° F. for 2 hr.
8½% nickel steel	Stainless steel	25–20 (Type 310)	1050° F. for 4 hr.
8½% nickel steel	Stainless steel	80% Ni – Cr Alloy	1050° F. for 4 hr.
8½% nickel steel	Stainless steel	25–20 (Type 310)	None
Stainless steel (Type 304)	Stainless steel	18–8 (Type 304)	None

All welds were made with 5/32-in. electrodes in one pass. A preheat of 200° F. was used for the 8½% nickel steel vessels although subsequent work indicated that preheat is unnecessary.

INSPECTION

After fabrication, major joints were completely X-rayed and defective areas (porosity) chipped out and rewelded. Each vessel was subjected to 700 lb. hydrostatic test. The pressure was maintained constant for approximately 15 min. without any drop in the pressure gauge or evidence of weeping.

COOLING

Tests were conducted to determine the liquid nitrogen level required to maintain a test temperature below −300° F. on the surface of the vessel. It was found that even when the vessels were well insulated there was a tendency for the outside surface temperature above the liquid level to equalize at a temperature well above −300° F., and it was concluded that the only means of insuring a surface temperature of −300° F., or below, was to test the vessels when filled with liquid nitrogen. Measurement of the surface temperature when the opposite surface was in contact with liquid nitrogen, gave readings within the range −305 to −320° F.

It was interesting to note that the liquid level in the vessels could be observed from the appearance of the outer surface. Heavy frost formed on the portion in contact with vapor, but dew (liquid oxygen from the atmosphere) formed on the portion in contact with liquid nitrogen. If the pressure was increased by stopping off the outlet, the entire outer surface frosted up.

LOW-TEMPERATURE TESTS OF VESSELS

Each vessel was filled with liquid nitrogen and subjected to impact loading by dropping a weight from a height of 5 ft. Details of the test jig are shown in Fig. 2. A tup with a ¾-in. spherical radius was attached to the bottom of the weight and formed the contact with the vessel except when the weight was dropped on the flange of the nozzle. In some instances to strike the desired location, it was necessary to rotate the vessel so that the nozzle, which was open, would be as much as 45° from a vertical position. Some of the liquid nitrogen spilled out, but as the weight was dropped within

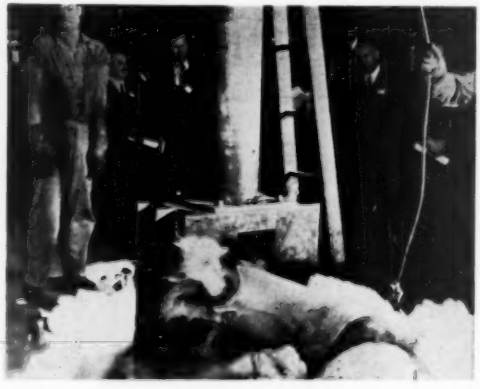

Fig. 3 Test of vessel filled with liquid nitrogen at instant of impact

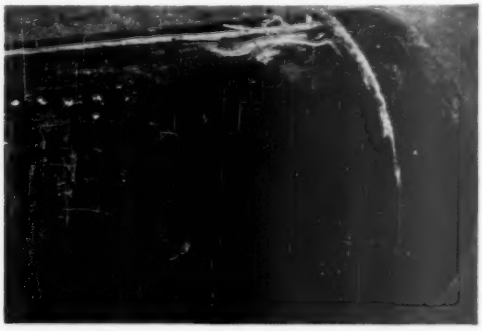

Fig. 4 Vessel of 8½% nickel steel, welded with 25–20 stainless electrodes, reheated at 1050° F. Tested at −320° F., 1500 ft.-lb.

Fig. 5 Vessel of 8½% nickel steel, welded with 80% Ni–Cr electrodes, reheated to 1050° F. Tested at −320° F., 1500 ft.-lb.

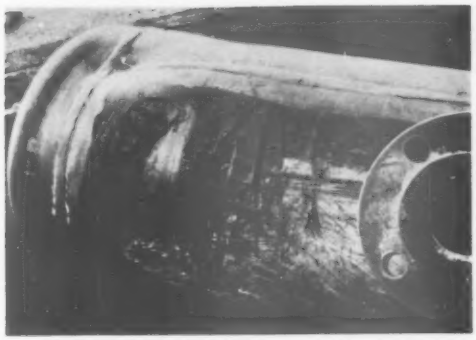

Fig. 7 Vessel of Type 304 stainless steel, welded with Type 304 electrodes. Tested as welded, −320° F., 1500 ft.-lb.

two or three seconds after the vessel was positioned, there was practically no rise in temperature in the wall of the vessel not in contact with the liquid.

A weight of 293 lb. (1465 ft.-lb.) was dropped on each of the three 8½% nickel steel vessels and on the stainless steel vessel. Each vessel was subjected to four blows at the following locations: (1) At the intersection of the longitudinal and circumferential seams, (2) at the longitudinal seam about 4 in. from the circumferential seam, (3) at the longitudinal seam near the nozzle, and (4) on the face of the flange of the nozzle. Attempt was made to locate the blow on the plate adjacent to the weld in the first three tests, but in several instances the tup struck at the fusion line. The vessels were filled with liquid nitrogen before each blow.

All of the 8½% nickel steel vessels and the stainless steel vessel deformed locally, but none failed. The dents in the stainless steel vessel were somewhat greater than in the 8½% nickel steel vessels due to the lower yield strength of the stainless steel. The appearance of these vessels after test is shown in Figs. 3 to7 , inclusive.

A weight of 185 lb. (925 ft.-lb.) was dropped on the carbon steel vessel in a location in line with the nozzle and about 4 in. from the longitudinal seam and a like distance from the circumferential seam. The vessel shattered badly on the first blow. The fracture, Fig. 8, did not follow any particular pattern and occurred also in the backing strip and head. Appearance of the fracture surface was crystalline with no indication of shear.

A lighter weight was used for the carbon steel vessel as the yield point was lower than for the other steels, and it was not intended to apply a force in the initial tests sufficient to cause the vessel to rupture in shear. At normal temperature (70° F.), only local deformation would have occurred with the force applied in this test.

IMPACT TEST OF VESSEL UNDER PRESSURE

An 8½% nickel steel vessel, welded with 25–20 stainless steel electrodes and reheated to 1050° F. was filled with liquid nitrogen and fitted with a control valve. The valve was adjusted to maintain an internal pressure of 100 psi., and the vessel was subjected to two blows (1465 ft.-lb.). The first blow was approximately midway between the head and the nozzle adjacent to the longitudinal seam, and the other was adjacent to the intersection of the longitudinal and circumferential

Fig. 6 Vessel of 8½% nickel steel, welded with 25–20 stainless electrodes. Tested as welded, −320° F., 1500 ft.-lb.

Fig. 8 Vessel of carbon steel, 1201, welded with carbon steel electrodes, stress relieved 1200° F. Tested at −320° F., 1000 ft.-lb.

Fig. 9 Vessels after test at 320° F.

seams. The surface temperature of the outer wall when the final blow was struck was −301° F.

No appreciable difference could be detected in the effect of testing the vessels in impact when filled with liquid nitrogen at atmospheric pressure, and when testing in impact when filled with liquid nitrogen at a pressure of 100 psi.

Facilities were not available to test at higher internal pressures without increasing the temperature.

TEST WITH 3000 FT.-LB.

The stainless steel vessel, one 8½% nickel steel vessel welded with 25–20 electrodes and reheated to 1050° F. and one 8½% nickel steel vessel welded with 25–20 in the as-welded condition were selected for testing under an impact force of 3000 ft.-lb. (2955 ft.-lb.—591 lb. dropped 5 ft). These vessels previously had been tested with a force of 1500 ft.-lb., but as one end of each vessel was undented, the vessels were so placed in the test jig that the effects of the previous tests had no influence. Each vessel was filled with liquid nitrogen and struck in two locations, in the wrapper sheet midway between the head and the nozzle, but away from the weld, and near the junction of the longitudinal and circumferential welds. In addition, the as-welded 8½% nickel steel vessel was subjected to a third blow at a position next to the circumferential weld between the two longitudinal welds. This was the only vessel that had two longitudinal welds, the reason being that the wrapper sheet was inadvertently cut too short and an extension had to be welded on. All tests were made on the vessels when filled with liquid nitrogen.

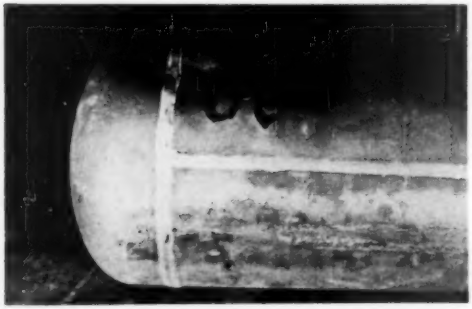

Fig. 10 Vessel of 8½% nickel steel, welded with 25–20 stainless electrodes, reheated to 1050° F. Tested at −320° F., 3000 ft.-lb.

The stainless steel vessel and the 8½% nickel steel vessel reheated to 1050° F. deformed considerably more than when struck with a 1500 ft.-lb. force, but no ruptures occurred and the vessels were still pressure tight. These vessels, after testing, are shown in Figs. 10 to 13. In Fig. 13, which is of the stainless steel vessel, the effect of the two different striking forces can be observed.

The 8½% nickel steel vessel in the as-welded condition successfully withstood the blow on the first two

Fig. 11 Vessel of 8½% nickel steel, welded with 25–20 stainless electrodes. Tested as welded, −320° F., 3000 ft.-lb.

Fig. 12 Vessel of 8½% nickel steel, welded with 25–20 stainless electrodes. Tested as welded, −320° F., 3000 ft.-lb.

Fig. 13 Vessel of Type 304 stainless steel, welded with Type 304 electrodes. Tested as welded, −320° F., 3000 ft.-lb.

tests, but with the third blow, which occurred between the two longitudinal welds and the circumferential weld, a small rupture occurred which ran parallel to the circumferential seam. This crack was only about 1/2 in. long. When this vessel was sectioned for examination after testing, it was found that the crack occurred at the edge of the backing strip and was a shear failure due to the stiffening effect of the backing strip rather than to lack of toughness in the plate. The crack can be observed in Figs. 11 and 12.

PROPERTIES OF MATERIALS AFTER TEST

There was not sufficient material available to determine the mechanical properties before the vessels were fabricated. Subsequent to the low-temperature impact tests, each vessel was sectioned and tensile and impact tests made on specimens cut from the vessel wall. Check chemical analyses are reported in Table 1. Results of tensile tests made on flat specimens of full wall thickness (approx. 1/4 in.) were as follows:

Charpy impact tests were made on specimens removed from the walls of the vessels after tests. It was necessary to prepare subsize specimens due to the gage of the sheet, and specimens keyhole notched across the narrow face. The values obtained permit comparison of the impact properties at room and low temperatures in thin gage material. The values are shown in Table 4.

CONCLUSION

Results indicate that small vessels of either 8 1/2% nickel steel or 304 stainless steel are capable of withstanding considerable shock at liquid nitrogen temperatures. It is recognized, however, that design is one of the most important factors in successful performance of a pressure vessel, and with changes in design and increase in wall thickness, results different from those obtained with these vessels might be experienced.

There is already some background of successful experience with vessels of stainless steel operating at very low temperatures, and it is anticipated that within the next few years there will be sufficient experience obtained on fabrication and use of 8 1/2% nickel steel to determine its ultimate position in the low-temperature field.

Table 2—Tensile Properties, Specimens Taken from Vessel Wall

Type steel	*Specimen location*	*Yield strength, psi.*	*Tensile strength, psi.*	*Elongation in 2 in., %*	*Elongation in 8 in., %*	*Brinell hardness**
Carbon	Wrapper sheet	47,200	71,000	31.5	23.5	149
8 1/2% nickel	Wrapper sheet, reheated 1050	86,000	108,000	24.0	13.3	229
8 1/2% nickel	Wrapper sheet, As-normalized	84,300	114,500	21.0	10.0	235
Stainless	Wrapper sheet, As-annealed	43,000	84,000	62.0	49.0	156

* Converted from Rockwell readings.

Due to the necking characteristics, elongation of 8 1/2% nickel steel in 8-in. gage length is low.

In both the carbon steel and the stainless steel, the weld was stronger than the plate which accounts for the normal elongation values. As the welds in 8 1/2% nickel steel were, in general, lower in tensile strength than the yield strength of the plate, all of the plastic deformation was confined to the weld metal, resulting in low total elongation. These values are shown in Table 3.

ACKNOWLEDGMENT

The author wishes to express his appreciation for the excellent cooperation of the staff of the Air Reduction Co., Apparatus Research Laboratory, and particularly to D.D. Snavely, who was in direct charge of the test

Table 3—Tensile Properties, Welded Specimens from Vessel Wall

Vessel	*Weld*	*Reheat*	*Yield strength, psi.*	*Tensile strength, psi.*	*Elongation in 2 in., %*	*Maximum Brinell hardness**	*Location of fracture*
Carbon steel	Carbon steel	1100° F.	32,000	59,300	16.5	156	Outside weld, head side
8 1/2% nickel	25–20 Stainless	1050° F.	47,300	84,500	7.0	235	In weld
8 1/2% nickel	80% Ni – Cr	1050° F.	48,500	85,000	6.5	229	In weld
8 1/2% nickel	25–20 Stainless	None	50,800	90,800	7.0	352	In weld
Stainless	Stainless (18–8)	None	40,200	85,300	53.0	170	Outside weld

* Converted from Rockwell readings.

Table 4—Charpy Impact Tests Results (Keyhole Notch) on Specimens Taken from Vessel Walls Specimens 0.394 by 0.197 In.

		Tested at 70° F.; location of notch			Tested at −320° F.; location of notch		
Steel	*Weld*	*Plate*	*Weld*	*HAZ*	*Plate*	*Weld*	*HAZ*
Carbon	Carbon, SR*	18 1/2, 17, 18	12, 15 1/2, 15 1/2	17 1/2, 17, 20 1/2	2, 1/2, 1	1/2, 1/2, 1	1/2, 1/2, 1/2
8 1/2% nickel	25–20, SR	27, 26, 25 1/2	15, 21 1/2, 20 1/2	20, 19 1/2, 21	17, 18 1/2, 18	16, 18 1/2, 17	17, 16, 8
8 1/2% nickel	80% Ni – Cr, SR	25 1/2, 27, 25 1/2	17 1/2, 19, 17 1/2	15, 15 1/2, 11	17, 17, 16 1/2	17, 18, 17	13, 14, 14
8 1/2% nickel	25–20, AW	25 1/2, 25 1/2, 25	20, 20 1/2, 19 1/2	14, 14 1/2, 10	17, 16, 18	15, 15, 17	12, 8, 8
Stainless	Stainless, AW	23, 21 1/2, 24	21 1/2, 22	20 1/2, 27 1/2, 21 1/2	32, 33, 29 1/2	14, 18, 16	22, 21, 22

* SR, stress relieved; AW, as-welded; HAZ, heat-affected zone.

work; to the M. W. Kellogg Co. for the design of the test vessels; to A. J. Miller, of the International Nickel Co., Research Laboratory, who performed the mechanical property tests; to the many individuals in the industry who offered suggestions on method of test, and to T. H. Wickenden, Vice-President and Manager of the Development and Research Division of the International Nickel Co., for his sustained interest and encouragement.

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(*Continued from page 14-s*)

cathode. Although we cannot give information on the effect, if any, of the surface condition of the cathode on the frequency of anode spot formation, nevertheless, the effect of its condition on the arcing process is profound. It is, of course, a well-known fact that small amounts of certain surface contaminants are capable of producing a marked effect on arc stability, and that it is a matter of difficulty for a welder to strike in air an arc between clean bright iron welding rods and a clean steel plate.[1]

In the same section of this paper, some interest would attach to the derivation of data from Fig. 11. In this figure, arc voltage is shown plotted against electrode separation, while in the text it is stated that the curve of total arc voltage against arc length is a straight line over the region studied, and that the slope of this line, 32 v./in., is the potential gradient in the arc stream for the conditions of test. Are we correct in assuming that such a statement implies that "electrode separation" has been taken as equivalent to "arc length"? Such an assumption would appear open to doubt, and indeed, from the drawings shown in Fig. 8, it would seem that, even for the carbon cathode, accurate arc length determination would be difficult, a difficulty accentuated in the case of a steel cathode by the rapid motion of the cathode spot, mentioned later.

Referring now to Figs. 10 and 11, and taking the following approximate figures—arc current, 65 amp.; anode spots per inch, 4.5; and anode spots per second, 156—it is seen from Fig. 11 that the arc voltage may be either 26 or 29 v., corresponding respectively to approximate electrode separations of $^1/_{16}$ and $^5/_{32}$ in.; while from Fig. 10 the arc-voltage reading for the electrode separation of $^1/_{16}$ in. quoted in the caption is 28.5 v., an apparent disagreement with the value of 26 v. from Fig. 11.

In addition, further information would be appreciated on the derivation of arc-voltage values from the oscillograms. Are the figures used "mean" values of the fluctuating arc voltage, or minima? For example, was the oscillogram in Fig. 6 used in the derivation of the arc-voltage curve shown in Fig. 11? The arc-voltage figure of 30 v. quoted on the oscillogram would appear to correspond with the approximate 29 v. read from Fig. 11 for an electrode separation of $^5/_{32}$ in. Judging from the oscillogram this would imply that arc-voltage figures are mean recorded values. If, however, the oscillogram corresponded to an electrode separation of $^1/_{16}$ in., then the arc-voltage figure of 26 v., read from Fig. 11, would relate to an approximate minimum value of arc voltage recorded on the oscillogram, although the spread of these minima is of the order of several volts.

In considering droplet formation with steel cathodes, the rapid and erratic motion of the cathode spot over the surface of the molten end of the electrode is commented upon by the authors. This is one of the features of the welding arc which makes it a difficult arrangement to deal with experimentally. It may be, of course, that this erratic motion is beneficial to the actual welding process, but it does imply also that electrode gap distances for such a setup may bear but little relation to actual arc length, a matter to which reference was made above.

Later in the same section of this paper the authors report that in a number of instances the short circuit produced by a large droplet was found to be followed almost immediately by a second short circuit of short duration. It may be that such a finding is in some way related to the method of test. For instance, from general data given in the paper, it would seem that, from the welding standpoint, the $^1/_4$ in. diameter steel electrodes were under-currented, while the rapidly moving electrode might produce premature rupture of the short circuit. Have the authors investigated the bearing of such factors on their results? As a matter of interest, we would like to add that, in our own work, using a steel rod to plate electrode arrangement, with stationary contacts, but with arcing duration automatically limited to short periods, we have found that a brief short circuit often precedes the longer duration short circuit. The time interval between the two shorts is of the order of a millisecond. A fuller account of the work referred to is now in process of publication.[2]

It is agreed that the provision of satisfactory explanations of the findings from such investigations as here considered are of importance in yielding a better understanding of phenomena which can have such an important bearing on practical processes such as welding.

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Tensile Tests of Small-Scale Welded Joints

Study of the relative effectiveness of Everdur brazing and steel welding in joining thin metal sections. Helium shielding improves strength and ductility of brazed joints

by T. D. Tuft

ABSTRACT

The relative effectiveness of Everdur brazing and steel welding in joining thin metal sections has been studied. Two sets of small-scale welded specimens each embodying four common types of joints were fabricated from black-iron sheet and tested in tension. One set was made with Everdur and the other with steel welds.

Welds of Everdur were not as strong or as ductile as those of steel. However, good Everdur butt welds may be expected to withstand stresses in the neighborhood of 30 kips. Helium shielding of the carbon arc used in Everdur brazing usually improved the strength and ductility of the welds.

Failures in longitudinal tee, longitudinal angle and longitudinal butt joints of both sets of welds were characterized by initial fractures in the weld beads. Failures in specimens with transverse butt joints occurred in the base metal except where the beads were filed down before testing.

A study of the effect of varying the width of tensile specimens showed that the behavior of standard tensile specimens provides only a limited index of the behavior of metal in a structure, as, for example, plating in a ship's bulkhead.

INTRODUCTION

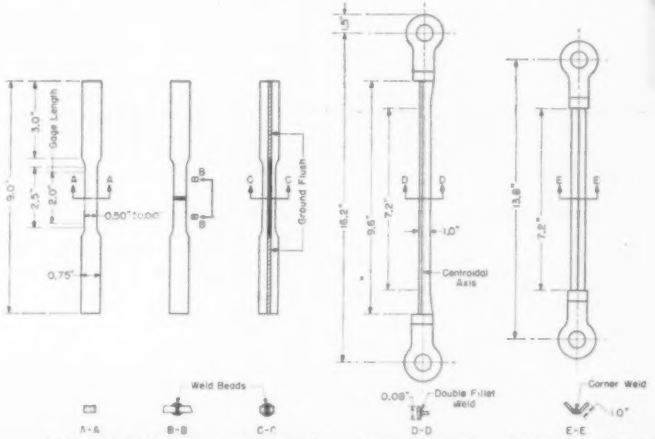
THE David Taylor Model Basin frequently builds and tests small-scale steel models of ship structures of welded construction. Some of these models involve steel less than 0.05 inch thick. Since the successful welding of fillets in such thin stock is impracticable if not impossible with the commercially available steel electrodes, the Taylor Model Basin usually substitutes Everdur brazing with the carbon arc for steel welding in making fillet joints in these thin plates. This process is especially advantageous in model-making, as it permits the joining of thin plates without the usual disadvantages of steel welding, e.g., high operating temperatures, burn-through, instability of the arc on small steel electrodes, large out-of-proportion deposits, and generally poor control. Everdur in models has proved satisfactory, but heretofore it has been used only in structures which have not been loaded beyond the elastic range or in which similitude of behavior at the connections has been of no particular interest.

The Taylor Model Basin was requested by the Bureau of Ships[1] to construct a $^1/_{10}$-scale model of a ship structure and to subject it to destructive test by underwater explosive loading. It is desired that the failures and fractures which commonly occur in the full-scale ships be reproduced in the model with reasonable accuracy in both type and degree. Specifications call for close similitude to the prototype in all structural details, with special emphasis on fidelity of behavior at the connections. Consequently an investigation of the structural properties of Everdur joints under both dynamic loading[2] and static loading was undertaken. This report is concerned with the static tests.

TEST PROCEDURE, APPARATUS AND SPECIMENS

The tests as originally planned included four common types of structural joints incorporated into small-scale tensile specimens which were tested to destruction in an Emery Tate testing machine of 30,000-lb. capacity. Samples of the four types of specimens are illustrated in Figs. 1 and 2. The test specimens included transverse butt joints which were loaded normal to the weld, longitudinal butt joints loaded parallel to the weld, longitudinal tee sections loaded parallel to the fillets and longitudinal angle sections loaded parallel to the corner welds. The specimens of butt joints were made by cutting ordinary flat tensile specimens in halves either transversely or longitudinally and then welding or brazing them together again.

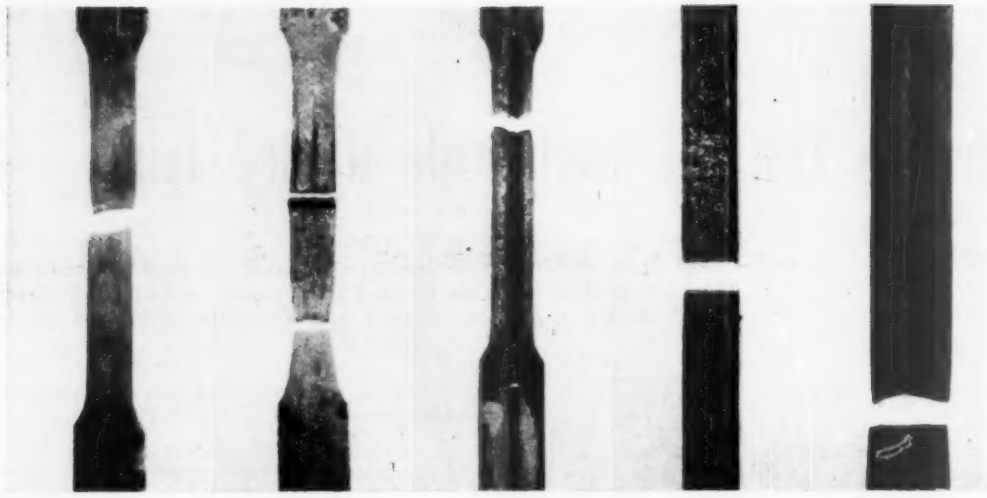
Specimens of each type of joint were made with Everdur, using the carbon-arc process for brazing. Similar specimens of the tee and angle sections were made with mild steel welding, using the ordinary



(a) Control (b) Transverse butt (c) Longitudinal butt (d) Longitudinal tee (e) Longitudinal angle

Fig. 1 Sample tensile specimens

T. D. Tuft is connected with the Navy Department at the David Taylor Model Basin, Washington, D. C.



(a) Control (b) Transverse butt (c) Longitudinal butt (d) Longitudinal tee (e) Longitudinal angle

Fig. 2 Fractures in specimens welded with Everdur

metal-arc process. Standard tensile coupons of the base metal were also tested. The base metal was black-iron sheet, the material which was to be used in the structural model. All tests were repeated on duplicate specimens.

Elongations in 2-in. lengths were measured in all specimens, and over-all elongations in the tee and angle sections were measured also. Elongations were taken with steel dividers from punch marks on the specimens and measured on a steel scale to the nearest 0.01 in.

Cross-sectional dimensions of all specimens were measured with micrometers before and after testing. The area of the weld beads was excluded in calculating stresses, unless otherwise indicated.

As the test program proceeded, a need for a few supplementary tests of specimens and joints of other proportions arose and such specimens were made and tested. These tests will be described later in this report in the section entitled "Supplementary Tests."

TEST RESULTS

Table 1 provides a comparison of the effectiveness of Everdur in the four types of joints tested. The data from tests of specimens of three thicknesses representative of those used in small-scale structural models are given and are compared with the unwelded, or control, specimens of the same thickness. Figure 2 shows typical fractures.

Tables 2 and 3 provide the detailed data from the tests of the tee and angle sections.

Table 1—Tensile Tests of Everdur Joints

Thickness of Specimen inches	Control	Transverse Butt*	Longitudinal Butt*	Longitudinal Tee Fillet	Longitudinal Angle Corner Weld*
			Maximum Stress† kips per square inch		
0.105	48 48	48 48 48	65 63 62	50 51	48 50
0.066	50 49	47 46	57 57 56	52 51	46 48
0.024	58 58	60 58	60 70 54	39 43	43 44
			Yield Stress† kips per square inch		
0.105	36 40	32 32 32	41 48 44	42 41	38 39
0.066	39 37	41 35	38 45 46	40 39	38 38
0.024	40 40	42 40	67 54	38 36	34 34
			Per Cent Elongation in 2 Inches		
0.105	37 38	30 28 30	8.6 7.0 7.0	18 18	12 14
0.066	33 34	26 26	6.5 6.1 6.0	8 8	5.5 7.5
0.024	22 19	20 20 18	0.5 6.0 0.5	0.5 2.5	4.0 4.0

* These welds were made using the helium-shielded carbon arc; the tee fillets were made with an unshielded arc because results of shielding with helium were not fully established at the time these specimens were made.

† The area of the weld beads was excluded in calculating these stresses.

DISCUSSION OF RESULTS

It should be noted that the wide variations which frequently occur in elongation and strength in two supposedly similar specimens are due mainly to variations in the human factor in the technique of welding. To produce weld beads of consistent size and quality is practically impossible, and in small-scale work the human factor is naturally magnified. Therefore, for the most significant com-

Table 2—Comparison of Full-Scale and Small-Scale Welded Tee Joints

Scale	Thickness inches	Length between Loading Heads inches	Specimen Number*	Temperature degrees fahrenheit	Yield Point kips	Yield Point kips/in²**	Maximum Load kips	Maximum Load kips/in²**	Elongation: Per Cent in Length L: L inches	Elongation: Per Cent in Length L: per cent	Elongation: Per Cent in 2-Inch Lengths: Top	Elongation: Per Cent in 2-Inch Lengths: Middle	Elongation: Per Cent in 2-Inch Lengths: Bottom
Full scale (4)	1.25	96.0	203-H*	65	673	33.7	1176	58.9	72.0	5.03			
			203-J*	16	674	33.7	1092	54.6	71.1	4.69			
Approximately 1/10 scale	0.135	9.6	6AE	Room temperature, approximately 72 degrees	12.3	54.6	15.5	69.0	7.06	14.7	12.0	10.5	20.5
			6BE		12.4	56.1	15.4	69.8	6.60	13.6	16.0♦	12.5	10.0
			6AS		12.8	57.1	16.8	75.3	6.80	15.4	14.5	15.5♦	17.5
			6BS		13.4	60.9	17.2	78.0	6.79	12.2	10.0	11.5	13.5♦
Less than 1/10 scale in thickness	0.108	9.6	5AE		7.60	42.2	9.05	50.2	6.75	24.4	18.0	30.0♦	24.5
			5BE		7.30	40.6	9.10	50.6	7.00	20.7	17.5	27.5♦	20.5
			5AS		8.14	44.8	10.1	55.6	6.78	16.5	19.0♦	13.5	13.5
			5BS		8.05	44.2	10.8	59.0	7.00	21.4	33.5♦	22.0	13.0
	0.080	9.6	4AE		5.50	39.8	7.57	54.8	6.98	9.74	8.0	12.5♦	8.5
			4BE		5.55	40.4	7.65	55.7	6.80	9.71	12.5♦	10.5	8.0
			4AS		5.90	42.8	8.50	61.7	6.00	17.5	23.0♦	17.5	13.5
			4BS		6.00	43.4	8.70	62.9	7.17	16.3	10.0	17.5	21.5♦
	0.066	9.6	3AE		4.50	40.0	5.85	52.0	6.00	10.0	14.0♦	8.5	8.0
			3BE		4.50†	38.9	5.85	50.6	6.00	10.0	12.5♦	10.0	8.0
			3AS		4.50†	39.2	6.64	57.9	6.00	18.7	20.0♦	18.5	17.5
			3BS		4.50†	39.1	6.60	57.3	6.00	18.8	17.5	24.0♦	15.0
	0.031	9.6	2AE		1.75	32.2	1.81	33.3	6.00	1.67	1.0	1.0	3.0♦
			2BE		1.70†	30.8	2.37†	43.0	6.00	3.85	4.0	3.5	6.0
			2AS		2.06	36.5	2.90	51.3	6.00	6.0	3.5	5.0	10.0♦
			2BS		2.20	39.6	3.30†	59.3	6.00	7.5	7.5	6.0	9.0♦
	0.024	9.6	1AE††		1.66	38.0	1.72	39.4	6.00	1.30	0.00	3.00♦	0.50
			1BE††		1.60†	36.3	1.89†	42.9	6.00	2.67	2.5	3.5♦	2.00

* Steel specimens are indicated by * or S; Everdur specimens are indicated by E.

** Stresses are based on the original cross-sectional areas excluding the area of the weld beads

† These values were taken from curves plotted from load-elongation readings. All other values of yield and maximum load were taken directly from the dial indicator of the testing machine.

†† These specimens were too thin to be welded with steel.

♦ The fracture occurred within this 2-inch length; when the break extended into this length the span of the break was subtracted before computing per cent of elongation. This was always done in the case of overall elongation.

Table 3—Comparison of Full-Scale and Small-Scale Welded Angle Joints

Scale	Thickness inches	Length between Loading Heads inches	Specimen Number*	Temperature degrees fahrenheit	Yield Point** kips	Yield Point** kips/in²	Maximum Load** kips	Maximum Load** kips/in²	Elongation: Per Cent in Length L: L inches	Elongation: Per Cent in Length L: per cent	Elongation: Per Cent in 2-Inch Lengths: Top	Elongation: Per Cent in 2-Inch Lengths: Middle	Elongation: Per Cent in 2-Inch Lengths: Bottom
Full Scale (4)	1.25	72.0	203-B*†	65	828	35.3	1490	63.6	68.5	20.6			
			203-D*†	65	698	29.6	1385	58.7	71.0	17.2			
Approximately 1/10 scale	0.121	7.2	EA6	Room temperature, approximately 72 degrees	11.4	54.3	14.4	68.7	7.0	8.01	8.0	9.0	9.5
			EB6		11.3	53.6	13.7	65.0	7.0	7.31	9.4♦	7.0	7.5
			SA6		12.0	56.4	15.6	73.9	7.0	17.9	13.5	22.5	24.4♦
			SB6		11.8	56.2	15.7	74.8	7.0	18.5	13.5	26.2♦	18.0
Less than 1/10 scale in thickness	0.107	7.2	EA5		7.20	38.1	9.00	47.6	7.0	13.2	14.5	19.7♦	14.0
			EB5		7.40	39.1	9.45	49.9	7.0	12.5	16.0♦	13.0	12.5
			SA5		8.10	43.1	10.3	54.8	7.0	21.7	21.5	28.4♦	23.0
			SB5		8.00	42.4	10.2	54.1	7.0	19.9	27.7♦	20.5	20.5
	0.079	7.2	EA4		5.50	38.0	7.90	54.6	7.0	9.30	10.0	9.5	13.6♦
			EB4		5.45	37.6	7.95	54.8	7.0	9.64	8.5	14.3♦	8.0
			SA4		5.70	39.7	8.65	60.2	7.0	17.2	24.7♦	18.0	15.5
			SB4		5.70	39.6	8.60	59.7	7.0	16.7	15.0	19.0	19.8♦
	0.065	7.2	EA3		4.60	38.2	5.50	45.7	7.0	5.64	9.4♦	5.5	6.0
			EB3		4.55	37.5	5.85	48.2	7.0	7.14	7.5	8.05♦	9.0
			SA3		4.60	37.9	6.50	53.6	7.0	10.6	10.0	9.5	11.5
			SB3		4.80	39.9	6.70	55.7	7.0	18.5	17.5	16.0	22.0
	0.0315	7.2	EA2		1.76	28.6	2.58	42.0	7.0	6.46	7.5	6.5	7.25♦
			EB2		1.70	27.8	2.63	43.2	7.0	6.60	7.5	6.0	8.95♦
			SA2		1.38	23.0	1.66	27.8	7.0	1.58	6.25♦	1.5	1.5
			SB2		1.55	26.2	1.56	26.2	7.0	0.389	2.7♦	2.5	0.0
	0.024	7.2	EA1		1.60	33.7	2.06	43.3	7.0	4.20	4.0	4.0	4.5
			EB1		1.60	33.8	2.09	44.1	7.0	4.34	4.0	6.75♦	4.5
			SA1		1.70	36.4	1.72	36.8	7.0	0.257	1.0	2.45♦	0.5
			SB1		1.78	37.9	1.80	38.4	7.0	1.71	1.5	1.5	1.5

* Steel specimens are indicated by * or S; Everdur specimens are indicated by E. All Everdur joints in these specimens were made with the helium-shielded carbon arc.

** These values were taken from the dial indicator of the testing machine; stresses are based on the original cross-sectional areas excluding the area of the weld beads.

† Specimen 203-B was straightened and normalized after welding; Specimen 203-D was shot-blasted and stress-coated after welding.

♦ The fracture occurred at this 2-inch length; when the break extended into the length the span of the break was subtracted before computing per cent elongation. This was always done in the case of overall elongation.

Table 4—Strength and Ductility of Everdur Joints as Affected by Shielding the Carbon Arc with Helium

Specimen		Per Cent Elongation in 2 Inches			Maximum Stress* kips/in²			Yield Stress kips/in²	Cracking Stress in Everdur** kips/in²	Yield Stress of Specimen kips/in²
Thickness inches	Width inches	Unshielded	Shielded	Control	Unshielded	Shielded	Control	Control	Shielded	Shielded
Longitudinal Butt Weld†										
0.105	0.505	4.0	8.6	38	56	65	48	36	46	41
		2.5	7.0		52	63			44	48
		6.0	7.0	40	60	62	47	40	43.2	
0.066	0.505	4.5	6.5	33	57	57	50	39	44	
		4.5	6.1		54	57			47	
		4.0	6.0	34	60	56	49	37	43	46
0.024	0.505	1.0	0.5	22	53	60	58	40	45	
		4.0	6.0		62	70			43	67
		1.0	0.5	19	52	54	58	40	36	
Transverse Butt Weld†										
0.105	0.505	24	30	38	46	48	48	36		
		21	28		48	48			No cracks	32
		3.0††	30	40	39	48	48	40		
0.066	0.505	6.0††	26	33	41	47	50	39		41
		22			45				No cracks	
		12		34	44		49	37		
0.024	0.505	3.5††	20	22	44		58	40		
		13	20		58	60			No cracks	42
		14	18♦	19	57	58	58	40		39

* The maximum stress is based on the original cross-sectional area excluding the area of the weld beads.

** The cracking stress is the load at which cracks first appeared on the Everdur divided by the total cross-sectional area including the area of the weld beads.

† Unless otherwise indicated the specimens were welded on both sides.

†† The specimen broke in the weld.

♦ The specimen was welded on one side only.

parison of the properties of welds as given in the tables of this report, extremely low values of strength and ductility should be ignored since they are probably due to local faults in the weld.

It was found that the quality of Everdur welds was improved by shielding the carbon arc in a reducing atmosphere. This was accomplished by using an electrode holder which maintained a flow of inert gas, helium, around the arc. The effect of the shielded arc is shown in Table 4, which gives the results of tensile tests of specimens welded with Everdur shielded and with Everdur unshielded and of unwelded control specimens. The results indicate definite improvement with the use of the shielded arc, especially in ductility. The stress at which the Everdur first cracked was noted in the test of specimens with longitudinal butt welds made with the shielded arc. Table 4 indicates that the Everdur rarely cracked until a stress greater than the yield stress of the base metal had been attained.

Table 1 provides a comparative summary of the quality of various Everdur joints, most of which were made with the helium-shielded arc. The tensile specimens welded with Everdur appear to have attained the full strength of the base metal except the thinnest specimens of tee and angle shape, which fractured at a stress approximately 30% below the maximum strength of the base metal.

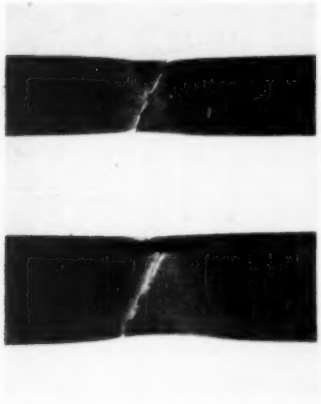


Fig. 3 Fracture in single-piece mild-steel tee section, showing simultaneous fracture across the section (Specimen 000)

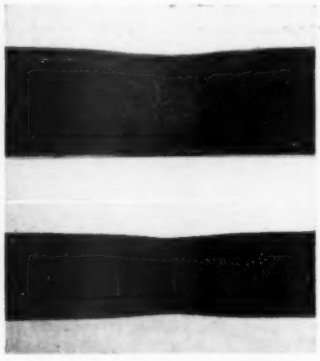


Fig. 4 Single-piece mild-steel tee section, showing no fracture after considerable necking (Specimen 00A)

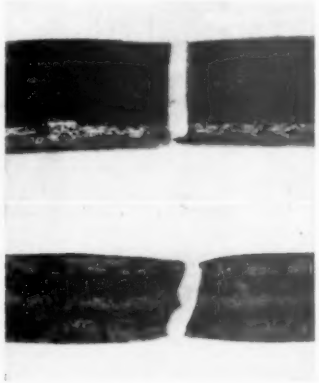
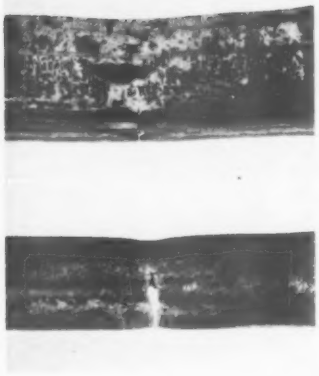


Fig. 5 Black-iron tee specimen welded with mild steel (Specimen 3BS) after complete fracture

The web, upper view, failed by tearing outwards after fracture started in the fillet. The lower view shows failure in the flange



(a)

(a) Web and flange views of Specimen 3BE. The upper view shows that the fracture, which started at the fillet, extended through the web and flange. The lower view shows the fracture in the flange

(b) Enlarged view of fracture in Specimen 3BE. This view shows that the fracture started in the fillet

Fig. 6 Fracture in black-iron tee specimen welded with Everdur (Specimen 3BE)

Table 1 shows that elongation in the brazed specimens was considerably lower than in the unwelded, or control, specimens, except in those with transverse butt joints. In these specimens the joint itself did not elongate appreciably; but yielding occurred in the base metal above and below the joint, as shown in Fig. 2.

In the longitudinal joints the Everdur always cracked before the base metal showed any signs of fracture, Fig. 6 (*b*). It has been shown in Table 4 that the load at which cracking of Everdur occurs is above the yield point of the base metal. For longitudinal joints it is therefore apparent that as the elastic limit of the black iron is exceeded and the base metal begins to yield, the Everdur must go along with it by correspondingly yielding, or it must crack. Since the Everdur is less ductile than the black iron, probably as a result of having absorbed some of the base metal, it soon cracks.

The tee- and angle-shaped specimens were patterned after large specimens which had been tested by the Carnegie-Illinois Steel Corp. in connection with its investigation of failures in welded merchant ships.[3] Except in the thickness, the dimensions were made to a scale of $^1/_{10}$ those of the specimens of the Carnegie-Illinois Steel Corp. The specimens were made in six different thicknesses. The specimen whose thickness was most nearly $^1/_{10}$ that of the Carnegie specimens thus provided a specimen of approximately $^1/_{10}$ scale. For each thickness four specimens were made, two joined with Everdur using the carbon-arc method and two joined with mild steel by ordinary arc welding.

(b)

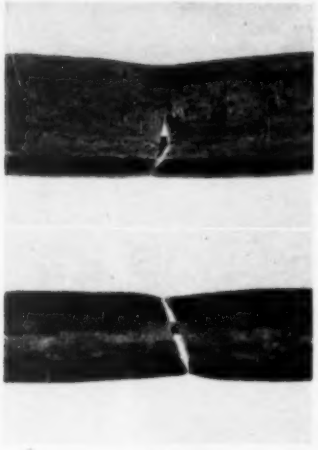
The tee and angle sections were attached to the loading heads in such a way that the load was transmitted along the longitudinal axis through the center of gravity of the specimens. This is illustrated in Fig. 1. Attachment to the loading heads was made by welding or brazing, depending on the thickness of the specimen.

Tables 2 and 3 give the detailed results from the tests of the tee and angle sections, respectively. Included are the data from full-scale specimens, which were taken from the reports by the Carnegie-Illinois Steel Corp.

Table 2 shows that the tee joints of Everdur which were nearest to actual $^1/_{10}$-scale thickness give higher values of yield, ultimate strength and percentage over-all elongation than the full-scale specimens. As regards the specimens whose thicknesses were not $^1/_{10}$ scale, the Everdur specimens of 0.08- and 0.066-in. thickness also compared favorably with the prototype; those of 0.031- and 0.024-in. thickness, although about equal to the prototype in yield stress, were considerably lower in maximum stress and in per cent elongation. Table 2 also provides data from the duplicate specimens welded with mild steel. In general the steel welds gave better results than the Everdur, but the specimens of 0.024-in. thickness could not be welded successfully with steel.

In Table 3, for the angle joints of 0.0315 in. or less in thickness, Everdur gave greater elongation than steel of the same thickness. In thicknesses of 0.065 in. or more the Everdur gave elongations considerably less than the elongation of steel. Maximum stresses varied correspondingly. Everdur brazing of these specimens was conducted in a reducing atmosphere, as explained previously. A comparison between the prototype and the angle section whose thickness was nearest $^1/_{10}$ that of the prototype shows that the small model with Everdur welding gave a yield stress about 65% higher and a maximum stress about 9% higher, but an elongation less than half that of the prototype.

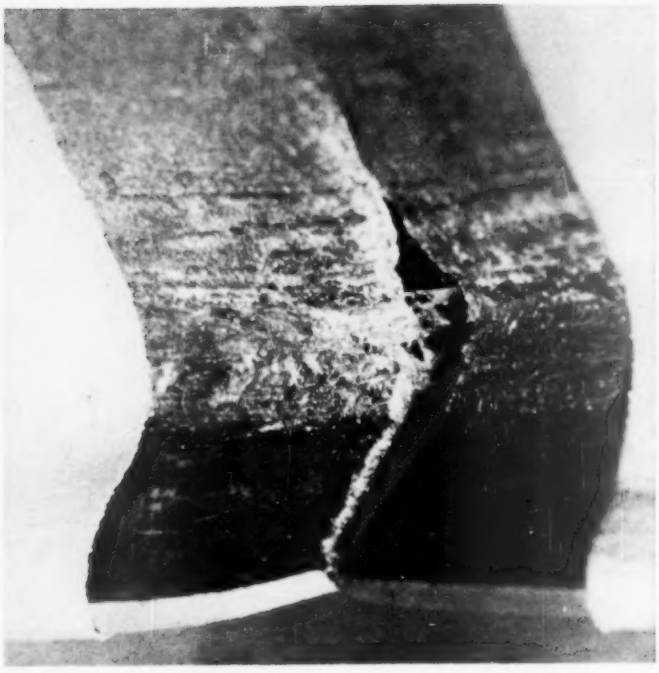
The results from the tests of tee and



(a)

(a) Web and flange views of Specimen 3AS. The upper view shows that the fracture, which started in the fillet, extended outward through the web and flange. The lower view shows the fracture in the flange

(b) Enlarged view of fracture in Specimen 3AS. This view shows that the fracture started in the fillet



(b)

Fig. 7 Fracture in black-iron tee specimen welded with mild steel (Specimen 3AS)

single specimens of thickness less than $^1/_{16}$ scale cannot be compared directly with those of the prototype since they are not true to scale. For example, if the specimens of 0.024-in. thickness had been made to $^1/_{16}$ scale in all their other dimensions they would have been roughly $1^1/_2$ in. long and slightly less than $^1/_4$ in. wide. To fabricate or to test welded tensile specimens of such dimensions would have been impracticable.

In the analysis of the test results it should be kept in mind that the small-scale Everdur brazed specimens were not necessarily intended to have the same structural qualities as the base metal nor as the duplicate specimens which were welded with steel. Since the objective is to reproduce the qualities, good or bad, of the full-scale structure, the pertinent comparisons are those between the $^1/_{16}$-scale specimens and the full-scale specimen or prototype welded with steel. Comparison of steel and Everdur in specimens made to the same scale is of secondary interest.

The mechanical properties and chemical analysis of the base metal of the small-scale specimens, i.e., black-iron sheet, and the metal that is most commonly used in full-scale structures, Grade M48-S-5 steel, are given in Table 5. The table indicates a reasonable degree of similitude in the mechanical properties of the metals.

SUPPLEMENTARY TESTS

The tensile tests of Everdur joints gave rise to certain questions which were given attention in a series of supplementary experiments.

MINIMUM WELD-BEAD REQUIREMENT

Figure 2 shows that Everdur transverse butt welds were of sufficient strength as welded to withstand the tests; the base metal yielded on either side of the weld joint, and failure occurred in the base metal. Table 1 shows that this failure occurred at the full strength of the base metal. A simple test was conducted to determine how large an Everdur bead is required in a butt joint to maintain full strength and ductility of base metal of 0.105- and 0.068-in. thicknesses. Three tensile specimens of each thickness with transverse butt joints were prepared for testing. One specimen was left as welded; the beads on the other two were filed down unequal amounts. Thus each of the three specimens had a different thickness of Everdur bead. The results of the tensile tests of these specimens are given in Table 6. From Table 6 it appears that an area of weld metal at least 50% greater than

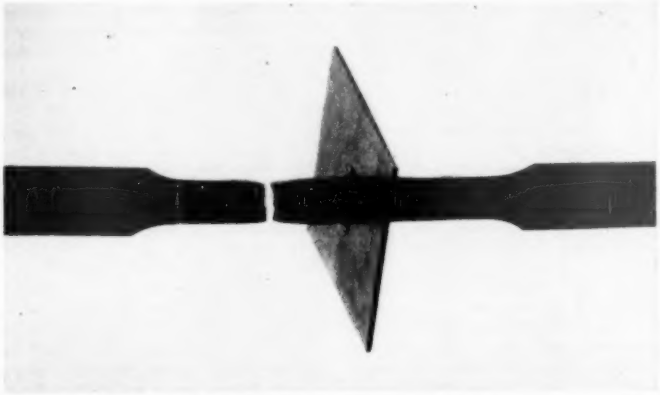


Fig. 8 Specimen used to test the holding strength of Everdur fillets. (The specimen broke about $^1/_2$ in. from the fillet)

Table 5—Comparison of Black-Iron Sheet with the Steel Used in Full-Scale Specimens and with Other Common Steels

	Black Iron*	Steel Used in Full-Scale Specimens (4)			Grade M48-S-5 Steel (5)	SAE 1010 Steel (1)	SAE 1020 Steel (1)
		203-B	203-D	203-H and J			
Mechanical Characteristics							
Tensile strength, kips per square inch	48.5 to 63	62.7	58	64.4	60 min.	67	75
Yield point, kips per square inch	32 min.	35.3	30	34.0	35 min.	55	63.7
Per cent elongation in 2 inches	22 to 47	32	35	34		25	20
Per cent elongation in 8 inches		26.5	34.2	31	24		
Per cent reduction of area	16.5 to 22.5	48.1	53.6	55.5		57	52
Brinell hardness	97					137	156
Chemical Analyses							
Carbon, per cent	0.04	0.26	0.22	0.23	0.31 max.	0.05 to 0.15	0.15 to 0.25
Manganese, per cent	0.33	0.53	0.37	0.47	0.75 max.	0.30 to 0.60	0.30 to 0.60
Phosphorus, per cent	0.030	0.023	0.016	0.030	0.045 max.	0.045	0.045
Sulphur, per cent	0.023	0.034	0.024	0.038	0.055 max.	0.055	0.055
Silicon, per cent	0.01	0.028	0.032	0.048	0.25 max.		
Copper, per cent	0.05	0.01	0.02	0.03	0.35 max.		
Nickel, per cent		0.03	0.03	0.04	0.25 max.		
Chromium, per cent		0.02	0.01	0.02			

* Physical data were taken from tests at Taylor Model Basin; the chemical analyses were made by the Naval Gun Factory, Washington, D.C.

the cross-sectional area of the base metal is required to develop the full strength of the base metal and good Everdur butt welds may be expected to withstand stresses in the neighborhood of 30 kips.

TENSILE TESTS OF SINGLE-PIECE TEE SPECIMENS

In the tests of the welded tee specimens, it was observed that failure apparently started in the fillet weld metal. However, in order to determine whether initial fracture was due to weakness of the weld or to the geometry of the section, i.e., whether failure would start at the junction of the web and flange anyway, a tee specimen was machined out of a solid piece of steel. Duplicate specimens were made with dimensions corresponding to those of the previously tested welded specimens of 0.066-in. thickness. They differed from the original specimens, however, in that the flange and web were not welded together, being of one piece, and the material was mild steel instead of black-iron sheet, which does not come in stock of sufficient thickness to permit machining a tee specimen from a single piece. This substitution was not considered objectionable, since chief interest was in the effect of the geometry of the section. Test results are given in Table 7.

The specimens differed somewhat from the welded ones in the manner of failure; that is, failure did not occur first at the juncture of the flange and web. Figure 3 shows that the one-piece specimens failed with a typical shear fracture after necking in both flange and web. Figure 4 shows the simultaneous necking in flange and web. The fracture appeared to occur simultaneously across the necked section rather than starting first at the center of the flange and/or the inner edge of the web as in the welded specimens; see Figs. 5, 6 and 7. It is indicated, therefore, that failures in the brazed and in the welded tee sections originating in the fillets were due to low ductility of the weld metal rather than to the geometry of the specimen. Figures 6 and 7 illustrate how failure in the welded tees apparently started in the root of the fillet.

Table 6—Effect of Weld-Bead Thickness on Strength of Everdur Transverse Butt Welds

Specimen Number	Specimen Width inches	Average Thickness of Weld Bead* inches	Maximum Stress kips/in² Base Metal	Maximum Stress kips/in² Everdur Weld**	Location of Fracture
Thickness - 0.105 Inch					
1	0.505	0.0525	45.6	22.8	Base metal
2	0.4865	0.0290	47.6	30.3	Base metal
3	0.4965	0.0225	38.8	27.5	Weld
Thickness - 0.068 Inch					
5	0.5	0.0270	46.8	25.5	Base metal
4	0.5	0.0125	45.5	33.3	Base metal
6	0.5	0.006	29.4	20.7	Weld

* Thickness was obtained by taking one-half of the over-all thickness at the joint minus one-half the thickness of the base metal.

** The maximum stress is based on the cross-sectional area of the joint before loading.

Table 7—Results of Tensile Tests of Tee Specimens Machined from a Single Piece of Mild Steel

Specimen Number	Maximum Stress kips/in²	Yield Stress kips/in²	Per Cent Elongation in 2 Inches
000	71	46	33.5
00A	78	47	32

TESTS TO STUDY EFFECT OF WIDTH ON STRENGTH AND DUCTILITY

In the full-scale tests of welded tee and angle sections which were conducted by the Carnegie-Illinois Steel Corp.,[3] standard tensile specimens were cut from the large specimens after failure and tested in tension. The small specimens gave a greater per cent elongation than the large specimens. In Reference 3 this difference was attributed to local faults in the welding of the larger specimens. Although this was probably the case, the question arose as to whether a small tensile specimen can be used to indicate reliably the behavior, especially the elongation, of a metal when used in a different geometric form; that is, can the deformation in a bulkhead under a certain tensile load be predicted from the deformation of a 0.505-in. round tensile specimen? Likewise, can the behavior of a bulkhead of, say, 5-in. width in a small-scale ship model be predicted from the behavior of a standard flat tensile specimen of $^1/_2$-in. width? There can be no doubt that tests of standard tensile specimens provide an excellent means of comparison of the mechanical properties of various metals, but they do not necessarily indicate the behavior of the metal in a structure.

An additional series of tests was therefore conducted to study the effect of the width of a tensile specimen on its strength and ductility. Tensile coupons of black iron were made in four different widths such that the widest specimen was 16 times as wide as the narrowest. The widths used were 0.125, 0.5, 1.0 and 2 in.

Table 8—Tensile Tests of Black-Iron Specimens of Four Different Widths for Two Different Thicknesses

Specimen	Dimensions						Maximum Load pounds	Maximum Stress lbs/in²		Elongation in 2 Inches after Break, Including Gap		Per Cent Reduction in Area
	Original			Ultimate				Based on A_o	Based on A_u	inches	per cent	100 × $\frac{A_o - A_u}{A_o}$
	Thickness inches	Width inches	Area, A_o square inches	Thickness inches	Width inches	Area, A_u square inches						
G-1	0.125	0.123	0.0154	0.111	0.111	0.0123	945	61.4	76.8	0.46 to 0.52	23 to 26	20
G-2	0.126	0.126	0.0159	0.114	0.117	0.0133	985	61.9	74.0	0.45 to 0.52	22.5 to 26	16
G-3	0.126	0.503	0.0634	0.109	0.447	0.0487	3,900	61.6	80.0	0.64	32	23
G-4	0.125	0.50	0.0625	0.108	0.446	0.0482	3,800	60.8	78.9	0.65	32.5	23
G-5	0.126	1.00	0.126	0.111	0.896	0.0995	7,700	61.1	77.4	0.72	36	21
G-6	0.125	1.004	0.1255	0.109	0.902	0.0982	7,650	61.0	77.9	0.77	38.5	22
G-7	0.126	2.0	0.252	0.101	1.70	0.1715	15,850	62.9	92.5	0.86	43	32
G-8	0.125	2.0	0.250	0.109	1.80	0.1962	15,800	63.1	80.5	0.94	47	21
G-1A	0.051	0.126	0.00642	0.047	0.116	0.00546	310	48.3	56.8	0.50	25	15
G-2A	0.051	0.125	0.00636	0.047	0.113	0.00532	310	48.7	58.3	0.45	22.5	16
G-3A	0.051	0.501	0.0251	0.046	0.471	0.0217	1,230	49.0	56.8	0.52	26	14
G-4A	0.051	0.502	0.0251	0.047	0.460	0.0216	1,260	50.2	58.4	0.57	28.5	14
G-5A	0.051	1.005	0.0504	0.047	0.925	0.0435	2,450	48.7	55.1	0.75	37.5	13
G-6A	0.051	1.004	0.0504	0.045	0.915	0.0412	2,550	50.6	61.9	0.65	32.5	18
G-7A	0.051	2.0	0.102	0.044	1.80	0.791	5,100	50.0	64.4	0.75	37.5	22
G-8A	0.051	2.0	0.102	0.046	1.78	0.820	5,050	49.5	61.5	0.75	37.5	20

Two sets of coupons were made, one of 0.125-in. thickness and one of 0.05-in. thickness.

The results of these tests are given in Table 8. Table 8 shows that the factor most affected by the variation in width was the per cent elongation in 2 in. By increasing the width from 0.125 to 2 in., the per cent elongations in the specimens of 0.125-in. thickness were increased 100%, and those in the specimens of 0.051-in. thickness 50%. Examination of the specimens after failure showed that this should be expected since the wide specimens necked down over most of their length whereas the narrow specimens necked down over only a small part of the 2-in. gage length. The change in width without a corresponding change in specimen length and gage length produced specimens that were no longer similar, and comparative values of elongation are not, of course, to be expected. However, the results bring out the need for exercising care in predicting the behavior of steel plating in structures from the results of standard tensile tests.

TESTS OF HOLDING STRENGTH OF EVERDUR FILLETS

Six specimens were prepared to provide a means of testing the holding strength of Everdur fillets. One of these specimens after testing is shown in Fig. 8. Ordinary flat tensile coupons were cut in halves transversely and the halves of each coupon were attached with Everdur fillets directly opposite each other on opposite sides of a 2-in. square of 0.06-in. black iron. This in effect, provided a double-tee joint in the tensile specimen. The helium-shielded carbon-arc process was used for the welding, and the fillets were made true to scale in correspondence with the thickness of the specimen. Two specimens of each of three thicknesses were tested.

Table 9—Tensile Test of Everdur Fillets in Black Iron

Specimen Number	Dimensions		Yield Stress kips/in²	Maximum Stress kips/in²	Per Cent Elongation in 2 Inches	Location of Fracture
	Thickness inches	Width inches				
1	0.101	0.502	30.8	46.6	16	Fillet
2	0.100	0.502	30.9	46.0	22	Base Metal*
3	0.057	0.502	32.4	43.2	23	Base Metal
4	0.057	0.502	32.5	44.0	24	Base Metal
6	0.031	0.502	24.5	43.7	22	Base Metal
7	0.031	0.502	24.1	43.5	22	Base Metal

* All fractures in the base metal occurred at least 1/2 in. from the fillets.

The results of the tensile tests of these specimens are presented in Table 9. The Everdur fillets as welded were of sufficient strength to prevent failure in the weld in five out of the six specimens tested. The maximum stress, yield stress and per cent elongation in 2 in. are consistent with the values previously obtained in control specimens.

CONCLUSIONS

Everdur brazing using the helium-shielded carbon arc does not provide as strong nor as ductile a joint as mild-steel welding, but Everdur can be used to obtain satisfactory welds in material that is too thin for steel welding.

Joints of Everdur in base metal ranging in thickness from 0.066 to 0.105 in. will sustain an elongation in 2 in. of at least 5%. In thicknesses less than 0.066 in., elongation may be as low as 0.5% and as high as 6%.

Everdur provides butt joints that are satisfactory both in strength and in ductility when load is applied normal to the joint. When thus loaded an as-welded joint is of sufficient strength to prevent failure in the joint itself.

The tests which were concerned with the effect of width have emphasized the fact that the per cent elongation in a standard specimen does not alone indicate accurately the behavior of similar material in a structure.

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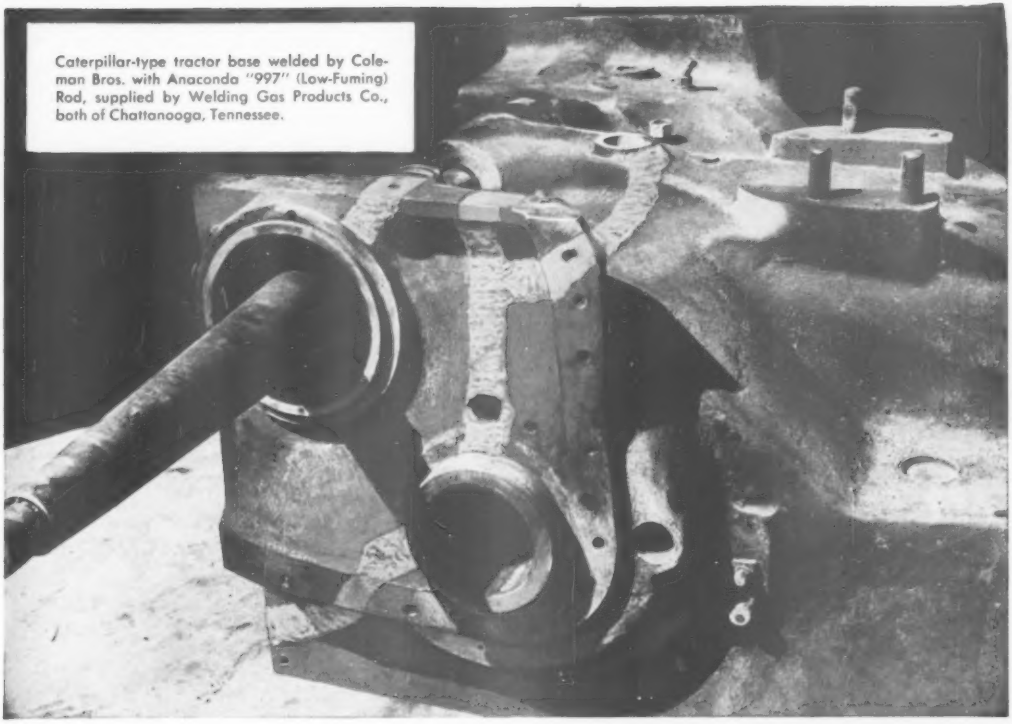

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